NGSS-BASED CONSTRUCTIVIST PEDAGOGIES: ONE SECONDARY EDUCATION TEACHER’S APPROACH TO DEVELOPING STUDENT’S SCIENCE IDENTITIES

Massa Mafi

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NGSS-BASED CONSTRUCTIVIST PEDAGOGIES: ONE SECONDARY EDUCATION TEACHER’S APPROACH TO DEVELOPING STUDENT’S SCIENCE IDENTITIES

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DISSERTATION

Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

Teaching, Learning, and Teacher Education

The University of New Mexico
Albuquerque, New Mexico

May 2022
DEDICATION

I dedicate this dissertation to my dear husband Arash, my beloved daughter Delara, my kind son, Artin, and my amazing parents, Mr. and Mrs. Massoud and Zohreh Safavian. Their unconditional love, enormous support, and never-ending encouragement made this work possible.
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ABSTRACT

This practitioner action research study explored features of NGSS-based pedagogies to improve secondary education student engagement, critical thinking, and collaborative problem-solving. It examined ways that constructivist pedagogies might encourage students to understand science by putting their skills and knowledge into practice as young engineers. The study involved 51 secondary education students from a large district in the southwest and focused on how NGSS inquiry-based learning can improve scientific understanding and skills within group work, the role that teacher support and modeling can play in learning, and how peer interactions
can influence their scientific identities. Qualitative findings from teacher observations, classwork artifacts, surveys, pre/post-tests, and Google Form responses provided a context for understanding student growth and changes in their science identities as they interfaced with the engineering design process. Using narratives and questioning techniques during the engagement part of 5E lessons provided opportunities for students to retain content information and the application of science in the real world. NGSS hands-on and technology-based activities contributed to flexible grouping activities that motivated students to learn science. Within these groupings, students collaborated with one another, presented their work, and were recognized for their contributions. In general, most students reported improvement in their learning of science concepts by self-discovery which strengthened their science identities. This study can provide in-service and pre-service science teachers with much-needed examples of how they might employ NGSS recommendations. Additionally, these examples can provide science educators with strategies for working with pre-service teachers to improve their confidence in teaching scientific concepts.
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1. Pre-Test Result

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CHAPTER I: INTRODUCTION

Background of the Study

With advancing technology, it is anticipated that the demand for qualified employees in science-related jobs, specifically in the physical sciences and engineering, will continue to increase. According to the U.S. Bureau of Labor Statistics (BLS), “[e]mployment is projected to grow by 8.4 million jobs to 169.4 million jobs over the 2018–28 decade” (BLS, 2019, p. 1) in the sciences and technology fields. Despite the growing high demand for these types of jobs, the current college enrollment rate in physical science-related areas is low. For example, based on the annual National Norms survey of American freshman, managed by the University of California, Los Angeles, researchers found that since 1971, 45% of first-year students specified that they intended to study science- and engineering-related fields (National Science and Engineering Statistics, 2018). While there was an 8% growth in science and engineering fields, compared to the year 2000, only 3% of freshmen planned to major in the physical sciences, while the other 42% of students planned to major in the biological and agricultural sciences (16%); in engineering (11%); in the social and behavioral sciences (10%); and in mathematics, statistics, or computer sciences (6%) (National Science and Engineering Statistics, 2018). More than half of the American students believe that STEM (science, technology, engineering, math) majors are difficult (Kennedy et al., 2018). Other factors are thought to be related to poor teaching quality and a lack of sense of belonging and motivation in STEM-related classes (Meyer and Marx, 2016). However, this sort of trend is not a new problem. As far back as 1950, the National Science Foundation (NSF) was established to initiate, support, and promote basic scientific research and education and evaluate the quality of the scientific research programs (Mazuzan, 1994). At
the time, the federal government also started funding K-12 education, including physical sciences, through NSF funding (Mazuzan, 1994). For example, Alan Waterman, a physicist at Yale University, was appointed as the first NSF director to provide government funding for high-impact research in science education. He also funded summer institutes for in-service and pre-service teachers, updating curricula and textbooks to improve K-12 education. That support was indeed focused on creating a link between K-12 and postsecondary education (Rudolph, 2002; Hassard, 2013).

According to Rudolph (2002), NSF’s engagement in K-12 education led to the exclusion of education professional organizations. Therefore, this exclusion profoundly affected the school curriculum, and it was the beginning of modern reform in science education (Rudolph, 2002; Hassard, 2013). According to Paul DeHart Hurd, as stated in Hassard (2013), “at some point an awareness emerges: the present curriculum is no longer serving the needs of either student or society” (p. 155). Indeed, the desire was to reform, not revise, the nation’s science and mathematics curriculum (Hassard, 2013).

As far back as 1956, under NSF’s funding, the first Physical Science Study Committee (PSSC), consisting of a group of physicists, was formed and commissioned to reform the teaching of introductory courses in physics. According to Hassard (2013), his committee concluded that the existing physics textbooks did little to stimulate the students’ interests in the subject; therefore, it was imperative to redesign textbooks. To do so, the PSSC leveraged the help of many scientists, teachers, writers, and artists and produced science textbooks, teacher guides, laboratory manuals, and many other educational resources. The new science textbooks, coupled with the modern curriculum, enabled evidence-based learning rather than learning by reading and memorizing facts from books (Hassard, 2013). The point was that
learning should be done by practice and experimental activities coupled with textbook-based education. While the textbooks provided the content knowledge, and the laboratory experiments brought deep understanding and connection to the knowledge, this deep understanding provided a deeper understanding of the content knowledge (Rudolph, 2002 & Belcher, 2017).

Despite the NSF team’s prior effort to improve secondary education, the NSF reduced the number of institutes for training in-service science teachers in 1957 (Rudolph, 2002). Over time, some academics and policymakers started questioning the school curriculum’s effectiveness, which had been designed to prepare students for social, personal, and professional life (NRC, 2006), rather than contributing to the emerging needs for the advancement of high technologies in the society. Eventually, a year later, the launching of the earth-orbiting satellite Sputnik by the Soviet Union started a new education reform to produce modern scientists and engineers to defend the nation from the ever-increasing threat by the Soviet Union. This was the beginning of a new era in science education (NRC, 2006).

According to Skinner (1984), on a morning in October 1957, Americans were awakened by the beeping of the Russian satellite, Sputnik: “Why was it not American? Was something wrong with American education?” (p. 947). Soon after this news, it was deemed that the United States needed “more trained scientists and engineers in many special fields, and especially very many more competent, fully trained teachers of science, notably in our secondary schools” (NRC, 2006, p. 22). In other words, the Sputnik launch influenced both the pedagogical approaches at schools and the teaching profession in American society (Swanek, 2012). Hence, science education found a new direction to rejuvenate the curriculum one more time.
Fast forward to the 21st century, and many national science education initiatives have made their way into the school curriculum. Most recently, the Next Generation Science Standards (NGSS) are one of the most significant developments in science education (NGSS Lead States, 2013). The NGSS started as a result of the collaboration between 26 states of the nation to offer new guidance for constructing science education based on the real practices of scientists and engineers (Next Generation Science Standards Lead States, 2013). This new framework was designed for K–12 science education to shift from teaching science ideas to helping students find out why phenomena occur or how to find solutions to problems—which cannot be separated from the doing of science. This change was a significant teaching revolution (Krajcik, 2015).

Although learning science content works as a tool for thinking and making sense of phenomena, it cannot be separated from the doing of science (Krajcik, 2015). Children need to be prepared for their role as informed and skilled citizens in the future, and schools need to better prepare the young generations by providing the knowledge and skills required to confront future challenges as citizens, parents, employees, businesspersons, and volunteers (National Research Council, 2012a). According to Krajcik (2015), in such classrooms, students can “build models, design investigations, share ideas, develop explanations, and argue using evidence, all of which allow students to develop important 21st-century skills such as problem-solving, critical thinking, communication, collaboration, and self-management” (p. 16).

Thus, educational reform currently emphasizes the importance of improving students’ critical thinking and creative problem-solving skills for the 21st-century workplace (Jenkins, 2013). According to Krapp and Prenzel (2011), almost all young children show interest and
enjoy new experiences, and they are also ready to learn about natural phenomena. However, from primary to secondary school, students’ preferences or interests are shaped based on their strengths and weaknesses, along with their personal experiences in science lessons (Krapp and Prenzel, 2011). According to Holbrook (2003), there is an urgent need to rethink science education. To prepare students to be functional in society, educators need to address the lack of popularity of science in schools and provide a robust awareness of science and technology within society (Holbrook, 2003). John Dewey (1913) believes that interest initiates attention, and attention is maintained through meaningful and engaging individual or collaborative activities that motivate further learning. Thus, inspiring and encouraging secondary students in a science class with teaching pedagogies that make learning personally meaningful, facilitate their learning, and promote their interests in science topics seems to be an effective way to encourage them to learn more about science. It can also prepare them for science-related careers in the future (Logan & Skamp, 2013).

According to the National Research Council (2007), middle school science’s main goal is to produce capable students who can think and act independently. Preparing students to become scientists, engineers, and other science-based professionals requires a great understanding and evaluation of information, reasoning skills, and best scientific decisions to integrate the information into action. To achieve this goal, the NGSS Common Core was proposed by a group of school administrators and governors to enhance student achievement (Kaufman, 2018). Therefore, providing engaging NGSS-based activities in a friendly competitive environment that leads to scientific thinking, processing, and learning seems to maximize students’ learning and interest in science and eventually raise the number of enrollments in science-related fields at the university level. To achieve this goal,
constructivist pedagogies that encourage the students to build their own knowledge via experiences, observations, documentation, analyses, and reflections seem to be effective (Bereiter, 1994). Student-centered learning is an essential component of a constructivist classroom. In such a classroom, “teachers encourage students to constantly assess how the activity is helping them gain understanding” (Bada & Olusegun, 2015, p. 66). From a pedagogical perspective, inquiry-oriented teaching is a method of constructivist teaching (Ng, 2010).

Furthermore, hands-on activities are shown to be an effective and enjoyable method for learning science (Hodson, 1990) because they engage students more by providing opportunities that allow students to test their own ideas and construct their own knowledge (Ewers, 2001). Indeed, inquiry-based learning through hands-on activities engages students by stimulating their interest and developing their understanding of science (Huber & Moore, 2001). According to Trnova & Trna (2011), hands-on activities play a crucial role in inquiry-based science education. Furthermore, working in groups allows the students to collaborate with others with new ideas, learn from those who might know better, and generate high-quality work based on effort and new learning ideas. According to Bruner’s point of view, “[a]n individual’s working intelligence is never “solo” (Bruner 1991, p. 3).

According to Heitmann et al. (2017), learning science is more about learning facts (p. 1). However, instead of focusing on fact-based science teaching, Henri Poincaré (1980) states in the National Research Council Publication, Taking Science to School: Learning and Teaching Science in Grades K-8 that “Science is built up of facts as a house is of stones, but a collection of facts is no more a science than a pile of stones is a house” (2007, p. 26).
Therefore, a method of teaching that elicits students’ interest is required to introduce a new topic. As a science teacher, I believe that teaching science through stories, and real-life examples give students a mental hook to grasp and remember the science content. Lemke (1990) also suggests narratives as a dialog strategy for teaching science and providing an opportunity for students to practice “talking science” (p. 98).

Narrative teaching that can put facts in stories or examples can also positively impact students’ motivation and learning (Graesser 2009, 260). In fact, “[g]ood stories engage people’s interest” (Gilbert et al., 2005, p. 12). Stories are not only extra information for the students, but they are the building blocks of understanding, learning, and remembering (Bruner, 1991). Students can perform better in science by sharing their narrative examples and stories, analyzing the information, and recognizing the “reality” (Bruner, 1991, p. 5). Thus, narratives provide a meaningful learning opportunity for students. Stories allow students to connect their background knowledge and learn through real-life experiences toward a broader understanding and longer remembering the science lessons. Finally, Elster (2007) emphasizes that constructivism impacts learning so that the teacher catches and holds students’ interest by making the subject of learning meaningful to them are, a promising approach.

Science and technology are highly integrated into our lives (Balkan-Kiyici & Kiyici, 2007). The growth of technology, enabled by scientific discovery, rapidly changes society and affects citizens’ quality of life. The utilization of science requires preparation for understanding technological innovation, leveraging the resulting tools and products, and recognizing the impact of technological products on life (NSB, 1983). Scientific and technological literacy is chiefly the proper understanding of science and technology
According to Dani (2009), scientific literacy is “the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity” (p. 289). Therefore, scientific literacy is the foundation of creating basic knowledge and effective strategies for developing, assessing, and improving technology.

Progress in science and technology necessitates emphasizing the impact of technology on society and requires a deep understanding of society’s influence on science and technology (National Science Teachers Association, 1982; Bybee et al., 1991).

Furthermore, “Students’ knowledge is not static, and proficiency involves deploying knowledge and skills” (National Research Council, 2007, p. 38). Hence the implementation of NGSS seems to support expanding students’ knowledge, skills, and critical thinking. Within this new framework, K–12 science educators teach science based on three dimensions: practices, crosscutting concepts, and core ideas (National Research Council, 2012). These three crosscutting concepts not only allow students to apply science and engineering practices; they also enhance students’ understanding of core ideas across the sciences (National Research Council, 2012).

**Statement of the Problem**

Historically, in the United States, education has served a unique role in providing free and accessible education for all students (Goldin & Katz, 2003). Despite the European countries such as Britain, France, and Germany that specialized in educating students with skills for a profession, the U.S. has provided mass general education for all students (Goldin & Katz, 2003). Thus, American students are trained not to lock themselves into one
professional field or learn one specific skill for life (Loo, 2018). This type of training is no longer useful with rapidly growing technology.

In this era, skilled specialists with strong critical thinking and problem-solving skills are needed to compete with the world. Unfortunately, United States students usually do not perform well on international tests, and they are not good predictors of U.S. success (Loo, 2018). For example, in the Program for International Student Assessment 2015, which every three years measures reading level, math and science literacy, and other essential skills among 15-year-olds in many developed and developing countries, the U.S. ranked 24th in science out of 71 countries (DeSilver, 2017). Hence, maintaining America’s global leadership in science and technology needs an education system that teaches the science content and fosters students’ critical thinking, creativity, and problem-solving skills (Loo, 2018). George Langford, head of the National Science Board’s education committee, also stated that “We face a looming crisis based on the country’s inability to train enough U.S.-born talent” (as cited in Mervis, 2003, p. 1).

Finally, the number of American students pursuing advanced degrees in physical sciences, astronomy, chemistry, and physics is dropping (Mervis, 2003). Even though the government has taken various systematic actions, American students’ participation rate in STEM fields is low, and the U.S. is dependent mainly on international students (Hossain, 2012). Despite the fact that the U.S has had one of the most robust higher education systems and has accepted international students globally, this number has dramatically declined due to the current political and cultural environment (Loo, 2018). The latest data based on a survey of approximately 3,000 accredited higher education universities from the Open Doors report, published annually by the Institute of International Education in cooperation with the
U.S. Department of State, showed that international student enrollment has dropped by 3.3% in the 2016-2017 school year (Baer, 2018). This rate declined even more in 2017 and 2018 by 6.6% (Baer, 2018; Redden, 2019) due to the political and cultural climate of not welcoming immigrants and foreigners (Loo, 2018). A recent report by Kennedy et al. (2018) indicated that 52% of American students believe that STEM fields are too difficult to study. One reason can be science's abstract nature and complexity (Piburin & Baker, 1993). Another study by Mamlok-Naaman et al. (2005) determined that interest and emotion are crucial in student attitudes toward science. They concluded that students do not pay attention to learning science if they find it boring. Based on these findings, Tseng et al. (2013) concluded that the main problem for lack of interest and negative attitudes toward school science learning is the curricula. They believe science teachers should offer more hands-on activities rather than focusing on theoretical memorization. Appropriate instructional strategies allow students to apply their knowledge into practice and enhance their learning by understanding science usage in real-life applications (George, 2006). Tseng et al. (2013) also concluded the importance of offering instructional strategies that positively impact student interests and attitudes toward science. Therefore, quality instruction is the most crucial component to fill this gap (National Science Board, 2016).

Unfortunately, there is also a shortage of highly qualified K-12 science teachers nationwide to provide such instructional pedagogies. Some scholars define highly qualified science teachers as certified, having subject-matter knowledge, having continued professional development, and they have access to instructional instructors and have suitable working environments (Campbell and Malkus 2011; Creemers et al. 2013; DeMonte 2013; Eckert 2013; Johnson et al. 2012; Schmidt et al. 2008; Shober 2012; Wilson 2011).
shortage is also evident in the National Research Council (NRC) report (2007) that says, “[a] US high school student has a 70% likelihood of being taught English by a teacher with a degree in English but about a 40% chance of studying chemistry with a teacher who was a chemistry major” (p. 113).

One approach that helps teachers improve their competencies to teach science is professional learning (Achieve, 2017). Science teachers need to learn how to create professional awareness and activities that involve but extend far beyond disciplinary content that enables all students to learn the next generation’s science (Council & National Academies of Sciences, Engineering, and Medicine, 2016). George (2007) showed that middle school and high school science teachers and their encouragement of science play a crucial role in student attitudes about science. Tseng et al. (2001) also recognized that teachers’ instructional pedagogy through STEM hands-on activities enhances students’ learning and attitude toward science. Therefore, the lack of teaching models and knowledge might cause many teachers not to understand how to teach science through NGSS (Nadelson et al., 2015).

Furthermore, the NGSS curriculum is expected to maximize the number of prepared students applying for high-needs, highly needed STEM jobs. The NGSS was developed to allow students to experience real STEM professionals by working on problems and projects (Nadelson et al., 2015). Unlike the STEM content standards, teaching K-12 NGSS has not been studied nor practiced sufficiently to integrate teachers into the NGSS teaching process, and more information should be developed on how the science teaching method is learned by students. Cohen (2015) recommends developing teachers’ and administrators’ collaborative networks within and across grades, buildings, districts, and states to address this issue.
Through such teaching collaboration, teachers will learn which of the lessons or units do not meet the expectations of the NGSS or are no longer used for a specific grade level by their district. Instead of trying and experiencing this new path in education individually, teachers can learn from one another, especially from those who are further on this path and have already implemented the NGSS in their teaching and have effective strategies to share with others (National Research Council, 2015).

**Theoretical Framework**

Vygotsky’s sociocultural theory will be used as a foundation for teaching and learning environments. Vygotsky believes that learning is a social process (Vygotsky, 1978). According to the National Research Council (2000), evidently “learning is enhanced when teachers pay attention to the knowledge and beliefs that learners bring to a learning task, use this knowledge as a starting point for new instruction, and monitor students” changing conceptions as instruction proceeds” (p. 11).

I will also consider the philosophical origin of constructivist theories of learning, which are attributed to the work of Jean Piaget (Steffe & Gale, 1995). In light of this view of learning, which is based on the processes that connect new knowledge to pre-existing knowledge (Berger, 2003), I will design an effective secondary science teaching pedagogy that addresses the essential principles of teaching and learning that are suggested by the literature. In a constructivist learning theory context, I will adopt the core guiding principles of educational constructivism to develop an effective teaching pedagogy that provides a secure and interactive classroom atmosphere in which learners can build meaning for themselves and learn science.
According to Gray (1997), the main principles of educational constructivism need to consider that students are active learners; the learning environment should be democratic; the activities need to be interactive and be student-centered; and finally, the teacher should be a facilitator. Thus, each student’s uniqueness based on their characteristics, such as pre-existing knowledge, learning experiences, language, culture, and interest, will be used to establish this constructivist teaching pedagogy. Furthermore, as defined by Chung (1991), a constructivist learning environment is characterized by,

1) shared knowledge between teachers and students,
2) shared authority and obligation among teachers and students,
3) the new position of teacher as an instructional guide, and
4) heterogeneous and small groupings of students.

Based on the above-suggested principles, different teaching and learning approaches can be used in a constructivist classroom. However, design practices must do more than accommodate the constructivist perspective. They should also promote the development of a powerful learning environment that maximizes the value of the epistemological principles (Tam, 2000). In what follows, I will explain some teaching approaches that support learners to develop the ability to learn science and advance their problem-solving skills in a socially active environment.

**Purpose of the Study**

This study aims to explore features of a student-centered NGSS-based curriculum to elevate secondary education American student engagement, critical thinking, creativity, and collaborative problem-solving. Moreover, this study hopes to inspire secondary students to
learn science by practicing it as young scientists and self-discoveries rather than through lectures, note-taking, and memorizations.

Additionally, I will use narrative stories to teach fundamental science concepts, and I will also use inquiry-based learning as a learning tool for students in a physical science classroom. Indeed, students might forget some of the scientific facts later in life. Using narrative stories will enhance remembering them as soon as they refresh their minds about the topic and quickly build more knowledge by connecting the new information to their background knowledge. Furthermore, establishing a positive student-teacher relationship can also improve students’ confidence and promote academic performance (Ryan et al. 1994).

While Gilbert et al. (2005) studied effective science pedagogies in New Zealand, the current study in 8th-grade physical science classes will provide better insight into teaching and learning science in the United States. In this study, qualitative analysis will be used to explore the effectiveness of particular teaching elements within constructivist pedagogies to improve critical thinking, learning processes, and engagement in science-related fields.

**Objectives**

1. To identify teaching elements within constructivist pedagogies in a physical science classroom that maximize students’ scientific thinking, learning processes, and interest in science-related fields.

2. To design and implement meaningful constructivist science teaching focused on the Next Generation Science Standards (NGSS).

**Aims**

My ultimate aim for this research is to understand how teaching pedagogies can
enhance 21st-century secondary education students’ understanding of science content in the United States.

**Research Questions**

1. How can inquiry-based pedagogies influence secondary education students’ problem-solving, concept development, and concept application skills in the science classroom?

2. What elements of inquiry-based teaching influence student engagement for science learning?

3. What role can teacher narratives play in understanding scientific concepts in a physical science classroom?

4. How can inquiry-based learning influence secondary education students’ science identities?

**Rationale and Significance of the Study**

Learning science provides individuals with fundamental knowledge and insight into the world and can contribute to learning specific skills such as problem-solving and critical thinking to enhance one’s life. Unfortunately, there is a shortage of highly qualified K-12 science teachers nationwide (NRC, 2007). Unlike the STEM content standards, teaching K-12 NGSS is not fully understood how teachers should teach and how students should learn it. Therefore, the lack of a teaching model and knowledge might cause many teachers not to know how to teach science through NGSS (Nadelson et al., 2015). This study will attempt to identify a potential NGSS teaching model or elements of a teaching model for teachers while also determining what elements of science teaching pedagogies maximize the students’ engagement and orient them to care about their learning in the science classroom. This
study’s approaches and findings may also help students further their scientific knowledge and personally benefit them throughout their lives and careers. This study could also help science teachers and administrators justify their teaching pedagogies and expectations for practice.

**Research Design Overview**

The sample size for this qualitative study will be about 50 eighth-grade students from a public school in a southwestern U.S. city taught by the teacher, who is also the researcher. Using an action research qualitative approach is to consider different views, experiences, positions, and perspectives (Johnson et al., 2007). Moreover, this research will be conducted as a self-study through action research. According to Loughran (2002), a self-study is a form of practitioner inquiry that enables educators to systematically reflect and study their practice to identify tensions or dissatisfaction. Action research is also the name given to an increasingly popular Educational Research movement. Action research allows a teacher to focus on his/her own experience to promote self-reflective research, which is also being used in school-based curriculum creation, career development, school improvement schemes, etc. (Campbell, 2013).

The current research will examine a physical science pedagogy’s critical factor in learning science that is engaging and enjoyable for American students. My goal is to inspire middle school students to learn science as young scientists and think scientifically through constructivist pedagogy. Narrative stories will be used to teach fundamental science materials, and inquiry-based learning will be used as a learning tool for 8th-grade students. The teacher will also establish a good student-teacher relationship to promote students’ confidence and maximize their academic performance (Ryan et al. 1994). Receiving support and positive feedback from the teacher might encourage the students to like the subject and pay more attention to learning.
Finally, using flexible grouping in middle school maximizes student engagement, interest, and performance by considering the students’ varying levels of skills and academic performance in a class (Russell, 2019). In this method, students can also take a role based on their capabilities and interest (Sandoval, 2013, as cited in Russell, 2019).

**Data Analysis**

Coding and interpretation will be used to analyze qualitative data. This allows researchers to have a professional vision of data (Goodwin, 1994). Qualitative data will be coded by hand and will be used as the first step for patterns across codes. Then, I will re-read the data to identify themes and categorize them based on my research questions. I will then document my findings and understanding of the data.

I will limit data collection to those participating in the study (Kang, 2013). For example, I will collect only the essential information through surveys and activities. For any missing or withdrawal data, I will look at each data set individually and determine the requirements based on the specific features and the effect of the missing data on the result.

**Limitations**

Every research study has its own limitations. It is essential to identify the weaknesses and origins of the limitations that influence the study’s result to help readers understand and generalize findings appropriately (Ross and Zaidi, 2019). The possible limitations in this study might occur because of the convenience sampling (Creswell, 2002). The common problem with this type of selection is under-representation or over-representation of particular groups within the sample (Lopez & Whitehead, 2013). The other limitation can happen due to non-response error, as a response rate of 100% is almost impossible to achieve (Sjöström et al., 1999). Bias can also occur at any part of this research, including data
collection, analysis, and interpretation (Small, 2009). According to Simundic (2013), “[b]ias is any trend or deviation from the truth in data” (p. 12). Finally, this study is also limited because it will be conducted solely in science classes of one school taught by one teacher and self-selection process to only volunteers (Simundic, 2013).

**Definitions of Terms**

*Next Generation Science Standards (NGSS)*

According to the National Research Council’s Framework for secondary Science Education, the Next Generation Science Standards identify what K-12 students need to know and be able to do at each grade level (National Science Teachers Association, 2012).

*Constructivism Theory*

The concept describes learning as an active and social process in which individuals actively construct meaning from their experiences and by connecting the new information to their prior knowledge (Driver, Asoko, Leach, Mortimer & Scott, 1994). Therefore, knowledge is not transmitted from the teacher “Knower” to the students “another” (Driver, Asoko, Leach, Mortimer & Scott, 1994, p. 5). Within this theory, students are no longer viewed as “passive recipients of knowledge,” and teachers are not “pursueryors of knowledge and classroom managers” (Fosnot, 1996 as cited in So, 2002, p. 4). Students will learn by trying to make sense based on their different experiences of what is taught. According to Duckworth (1987), “[m]eaning is not given to us in our encounters, but it is given by us, constructed by us, each in our own, according to how our understanding is currently organized” (p. 112).

*Inquiry-Based Learning (IBL)*
According to Zambak et al. (2017), IBL is defined as any planned student-centered instruction that allows the student to deepen their understanding of scientific content through purposefully designed experiences. Therefore, an inquiry is referred to as a multilayered activity that involves,

making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze and interpret data; proposing answers, explanations and predictions; and communicating the results” (National Resource Council, 1996, as cited in Fradd, Lee, & Sutman, 2001, p. 480).

This study also uses the unit of “forces and motion” and “forces and interactions” interchangeably.
CHAPTER II: REVIEW OF THE LITERATURE

The Sociohistorical and Contemporary Sociopolitical Context of Teaching Science

The history of the United States indicates that scientific practice and science education were placed into a more structured form at the end of the 19th century (Bybee, 2010). This is mainly due to the shift from basic commodity-based industries such as iron, steel, and coal to new innovation-based industries such as chemical, optics, and electricity (Bruland, 2004). The industrial revolution was initiated in Great Britain but soon after migrated to mainland Europe, especially Germany, and eventually made it to the United States. By the late 19th century, Germany and the United States pioneered and developed specialized research and development (R & D) departments and laboratories (Bruland, 2004 & Matthews, 1994) that led the technological innovation. The growth of industry captured the public interest, which considerably increased the rate of high school enrollment between 1890 to1900 (Belcher, 2017). In 1892, the National Education Association appointed the nation’s first blue ribbon education commission to suggest secondary education standards that prepared students for life, society, and college. This commission, The Committee of Ten, was composed of educational leaders and scientists and was chaired by Charles W. Eliot, president of Harvard University (Kirst & Usdan, 2009). This committee established a standard curriculum with two major recommendations: the earlier introduction of physical sciences in the teaching curriculum and teaching these subjects to all the students regardless of their choice to head to a college or industry after high school (Mackenzie, 1894). In order to specify the exact requirements for laboratory experiments in secondary education, the physics department at Harvard University developed a list of Elementary Physical Experiments. This list grew over time, and more information was added by other universities, which eventually led to the
development of the first National Science Education Standards (National Research Council (NEA), 1996 & Bybee, 2010). The establishment of the College Entrance Examination board is another legacy of this committee (Ravitch, 2000 & Vazquez, 2006).

According to NEA (1893), the Committee of Ten recommended that 25% of the yearly high school curricular time should be spent on science. Despite this recommendation, Vazquez (2006) claimed that students spent only about 15% of the curricular time in science at his publication time. Although specific reasons and detailed information for this 10% lower curricular time for secondary science are somewhat unclear, it is thought to be because of students’ enrollment in only one science course per year instead of more (Vazquez, 2006). The Committee of Ten also made a recommendation on spending about 60% of the high school science courses on laboratory work. Simultaneously, a national survey in 2000 indicated that most of the instructional time was spent in lectures and not in a laboratory with hands-on activities (Wood, 2002). Some of these discrepancies may be rooted in the fact that the grade placement of different science subjects was not discussed or recommended by the Committee of Ten (Sheppard & Robbins, 2007).

Nevertheless, the development of uniform standards for each academic subject provided a clear path for students’ college examinations and admissions (Kirst & Usdan, 2009). After World War II, K-12 academic standards received less attention, and elective courses in nonacademic areas became more important for universities’ admissions. Furthermore, evaluations by the K-12 standards were replaced with aptitude tests such as the Scholastic Aptitude Test (SAT) for college entrance (Vazquez, 2006).

**Curriculum Ideologies**

*The Scholar Academic Ideology*
According to Kirst and Venezia (2004), in early 1950, the national groups began to reshape the secondary academic curriculum based on the Committee of Ten’s original vision, but they faced mixed results. A large gap was also produced between high school and college education in the U.S. compared to other industrialized countries (Clark 1985 & Callan et al., 2009). Kliebard (2004) highlights the relationship of the curriculum’s complexity to major curriculum ideologies from 1893 to 1958. For example, according to the Committee of Ten, the school’s central vision and goal were to transmit the knowledge, cultural, and traditional values of Western civilization (Kilebard, 2004). Based on this perspective or the Scholar Academic Ideology, teachers needed to be knowledgeable and have academic degrees in the subjects they taught to effectively transfer the knowledge to the students. Moreover, the students needed to enroll in college preparatory classes in high school until their minds grew in the academic hierarchy and they became good citizens (Schiro, 2008).

While the academic scholars justified such a liberal-arts curriculum as the best method of education, there were other groups with different perspectives, such as humanists who believed in cultural tradition as an individual’s intrinsic values (Kliebard, 2004). The following are three other educational ideologies from other scholars.

**The Learner-Centered Ideology**

Granville Stanley Hall and William Head Kilpatrick were among educators who strongly believed in curriculum structure based on child development, i.e., a child-centered curriculum. In such a curriculum, instructions should be designed based on individuals’ different learning capabilities that attract students’ interest during each growth stage (Labaree, 1987; DuCharme, 1993; Kliebard, 2004). They also believed that learners grow and learn through interactions with their physical, intellectual, and social environments.
Since individuals’ experiences and interactions are unique, the context and the learning environment should be well designed with deliberate and relevant context for each learner (Schiro, 2008).

**The Social Efficiency Ideology**

Another group, including Leonard Ayres, John Franklin Bobbit, Charles Ellwood, Ross Finney, Charles Peters, and David Snedden, were among the social efficiency educators who believed that the school system should prepare the students for their future occupational roles as adults in society. From this perspective, they believed that the curriculum should address students’ needs based on their roles in adulthood in society (Labaree, 1987).

**The Social Reconstruction Ideology**

Finally, the fourth group, including George S. Counts, Harold O. Rugg, and Lester Frank Ward, had a curriculum ideology that was based on social reconstruction (DuCharme, 1993 & Kliebard, 2004). This group believed that many problems threaten society’s survival, such as “racism, war, sexism, poverty, pollution, worker exploitation, global warming, crime, political corruption, population explosion, energy shortage, illiteracy, inadequate health care, and unemployment” (Schiro, 2012, p.133). Thus, this group recommends taking direct action toward these problems to have a healthy society (Labaree, 1987 & Schiro, 2012). One method is to design a school curriculum that teaches a new social vision of justice and equality for “the masses of humanity” as a tool to improve society and prevent it from further disruption (Schiro, 2012, p.133). This school of thought views students as the “products of society” or “social actors” who need to be prepared for future related tasks to aid in the reconstruction of society (Schiro, 2008, p. 157).

**Changing Goals of Secondary Science Education and Reform**
Despite the significant care and investment in education for more than 30 years since the beginning of NSF, Americans still were being awakened by new math and science-based inventions by other countries, such as modern Japanese cars, radios, phonographs, and television sets (Skinner, 1984). During Reagan’s presidency, the Nation at Risk report was published (NCEE, 1983). The report was focused on the quality of American education. The National Commission drafted the report Excellence in Education (NCEE) in 1983. The report emphasized that the risk is not only in remaining competitive with other countries such as Japan or South Korea to make more advanced and efficient machines, tools, and automobiles, but it is more about the intellectual, moral, and spiritual strength of the Americans. Therefore, “A high level of shared education is essential to a free, democratic society and the fostering of a common culture, especially in a country that prides itself on pluralism and individual freedom” (NCEE, 1983, p. 10).

The Nation at Risk report resulted from an eighteen-month study that showed the secondary school curricula were not unified and effective for all the subjects. Many American students and even adults were functionally illiterate (NCEE, 1983). Therefore, modifying the educational system that elevated student achievement was presumed to influence the quality of the scientific and technological fields as well as the U.S. economy. Five fundamental factors were suggested to be added to the school curriculum to improve the curriculum and maximize student achievement. It was recommended that students take four years of English, three years of social studies, math, and science, and half a year of computer science during secondary education. A new standard was also established for what students needed to learn to achieve excellence by taking these classes. The NCEE specified excellence
as “a school or college that sets high expectations and goals for all learners, then tries in
every way possible to help students reach them” (NCEE, 1983, p. 14).

Skinner (1984) published *The Shame of American Education* only a year after *A
Nation at Risk: The Imperative for Educational Reform*. He indicated that the essential
factors to improve the educational system are the clarity of educational goals, understanding
the individual differences, and providing opportunities for them to learn based on each
person’s own pace. He also mentioned that the teacher’s training and technology integration
are the key components of better and effective teaching pedagogy (Skinner, 1984).

According to the *Nation at Risk* report, “the educational foundations of our society are
presently being eroded by a rising tide of mediocrity that threatens our very future as a
Nation and a people” (NCEE, 1983, p. 9). Skinner emphasized that the causes and effects
were mistakenly interpreted in this reform, and mediocrity was not the cause of erosion. He
stated that “[O]ur educational foundations are being eroded by a commitment to laymanship
and to theories of human behavior which simply do not lead to effective teaching” (Skinner,
1984, p. 953).

Skinner takes issue with President Reagan’s quote declaring that “this country was
built on American respect for education. . . . Our challenge now is to create a resurgence of
that thirst for education that typifies our nation’s history” (Raizen, 1983, p. 1, & Skinner,
1984, p. 953). His main objection is to the correlation established in this declaration by
President Reagan between respect and education. He asks;

> is education in trouble because it is no longer held in respect, or is it not held
> in respect because it is in trouble? Is it in trouble because people do not thirst
> for education, or do they not thirst for what is being offered? (Skinner, 1984,
Skinner (1984) reiterates that the educational system’s failure is not the fault of the students, teachers, or schools. In fact, we cannot blame the students when they have not been well taught or teachers when they have not been adequately trained to teach. Therefore, developing effective and attractive instructional practices that encourage students, teachers, and administrators to use them in teaching and learning is needed. Skinner proposed behavioral sciences’ contribution as part of a solution to this issue to educate the students about the advantages of education for a stronger America (Skinner, 1984). Skinner used the Sputnik Russian Satellite as an educational, political, historical, and cultural lesson that needed to be transferred to new generations to perform better as a nation. In this respect, American education went under another reform when Halley’s comet was first observed a couple of years later.

Project 2061

F. James Rutherford established project 2061, or systematic reform, at the American Association for the Advancement of Science in 1985 (Alvarado, 2013). It was the same year that Halley’s Comet was visible from the Earth. The expert panels from different science fields gathered to identify K-12 teaching and learning’s essential principles that enable the next generation to be science literate. The goal was set for the next 75 years when Halley’s Comet returned to Earth’s vicinity. This project was designed based on science, math, and technology principles for effective teaching and learning that make all individuals science-literate (Alvarado, 2013).

Project 2061 did not focus on the details of the curricula and instruction; instead, it primarily focused more on highlighting what was worth learning for the students to retain
after high school graduation. It pointed out that the importance and beauty of science could be understood mostly by those who are science-literate (Alvarado, 2013), and science needed to be taught to all individuals and not only to future scientists or engineers. According to Alvarado (2013), the excitement comes with “finding out who we are, where we are, how we relate to all living things and to our natural surroundings” (p. 2). Therefore, Project 2061 experts recommended, “biological and health sciences, social and behavioral sciences, physical and information sciences, engineering, mathematics and technology” be taught to all K-12 students regardless of their background and socioeconomic status, including “race, ethnicity, culture, gender, economic circumstances, physical limitations and location” (Alvarado, 2013, p. 3). The curriculum then needed to be built based on equity and equality, such that all the students could gain the knowledge and learn the required skills for their future as adults. In addition, the curriculum must guide students to understand the broader scope of science, including mathematics, physical and social sciences, and technology, and develop their scientific literacy to view the world through the eyes of science (Alvarado, 2013). Some critical aspects of such desired scientific literacy include:

- Gaining knowledge about the physical world, including its diversity and unity.
- Understanding the principles of science and conforming to scientific thinking.
- Appreciating the connections between mathematics, physical and social sciences, and technology.
- Awareness of the strengths and limitations of sciences as they are human enterprises.
- Leveraging the scientific knowledge for individuals and social purposes (Alvarado, 2013).

In 1993, they published the benchmarks focusing on content standards or the specific
basic learning goals for grades 2, 5, 8, and 12. Another principle in this reform was to teach all subjects centered around science literacy. Finally, schools needed to teach less but for a longer-term so that the students could learn the content better (Alvarado, 2013).

This project was designed to make the students ready and informed about observing Halley’s Comet in the year 2061. It was also intended to promote science literacy for all Americans. Project 2061 provided a foundation reform by offering an education that prepared the students with the wisdom, information, and fundamental skills required for an advanced science and technology world in the future (Alvarado, 2013).

Much has already been done, and much remains to be accomplished yet (Alvarado, 2013) to make American students passionate about learning science with the goal of enhancing their quality of life with the power of advanced technology. Patience, extra assessments, and financial and human resources seem to be essential in this educational reform (Alvarado, 2013). To achieve this goal and maximize students’ engagement, National Science Education Standards (NSES) suggested a shift from traditional teaching, which is transmitting knowledge by teachers, to more problem-based and inquiry-oriented instructional approaches (National Research Council, 1996 & Alvarado, 2013). Dewey (1910) believes that learning the processes and methods in science is as vital as learning content knowledge. Dewey was a prominent educational philosopher (Theobald, 2009) of the 20th century, also known as the father of modern education (Williams, 2017). According to Dewey (1938), education at school needs to be aligned with real-life situations and challenges. Flexible learning activities should be offered to students to participate interchangeably in various social settings (Dewey, 1938). Dewey argues that learning occurs based on experiences, and individuals need to construct and reconstruct their experiences to
learn. On the other hand, teachers should actively be involved in this process to develop effective understanding and learning (Dewey, 1916).

Providing a good K-12 education has been a concern in the United States for many years (Skinner, 1984). There is no doubt that all children can learn (Finke, McNaughton, & Drager, 2009); however, lack of funding and adaptation of effective teaching strategies to different situations and circumstances seem to be the main issue in our educational system.

**No Child Left Behind**

One of the major educational reforms in the United States in the past two decades was the No Child Left Behind (NCLB) Act. President George W. Bush signed the NCLB Act in 2002 (U.S. Department of Education, 2007). The purpose of this act was to ensure that all the students in public schools received high-quality teaching to become proficient in mathematics and reading in a safe environment and be able to graduate from high school. According to Cortiella (2006), the goal of NCLB was “to ensure that all children have a fair, equal, and significant opportunity to obtain a high-quality education and reach, at a minimum, proficiency on challenging State academic achievement standards and state academic assessments” (p. 6). NCLB was made up of four principles: accountability by setting goals; flexibility by offering federal money to the classrooms where it is needed most and allocating more federal support for education; research-based reform in which schools needed to use evidence-based practices and materials; and finally, the parental involvement and options to make a change when their child’s school does not improve (U.S. Department of Education, 2006).

According to the U.S. Department of Education (2006), under the NCLB Act, every school had to show significant yearly progress in core subjects of mathematics and reading.
Third-grade through eighth-grade students would be tested annually, but only once in high school. More funding would be given to failing schools to provide necessary accommodations to improve students’ scores. The schools that were not able to enhance scores would then face sanctions. After two years of failure, the students would have an option to move to a better school. After three years, if these students could not transfer, the students could receive free after-school tutoring. After four years, the school would need to make fundamental changes, such as firing underachieving teachers, and finally, the school would have to be restructured (U.S. Department of Education, 2006).

Although the NCLB Act was a tremendous educational enterprise to ensure that every child had access to good education and to close the achievement gap, Congress became aware of the growing achievement gaps fueled by the NCLB Act due to leaving only poor and minority students in failing schools (Klima, 2007). The real outcome of the NCLB Act was that the evaluation of schools’ effectiveness was mainly based on the type of students in each school rather than the quality of the teaching. In some cases, the teachers were even encouraging students who performed poorly on exams to drop out to save the school from legal intervention. During the 2001-2002 school year, the rate of the students who dropped from the Chicago Public School was 17.6% of the total enrollment, which amounted to about 17,400 students (Klima, 2007, p. 20). Illinois Superintendent of Education Robert Schiller explained that the NCLB was the main cause of this high drop-out rate. Moreover, each state had its own standards and tests because education was legally a state right, not a federal right (U.S. Department of Education, 2016; Klima, 2007, p. 5-6).

One of the adverse side effects of evaluating success based on standardized assessments is that many teachers would focus their attention on teaching only specific subject awareness
and related skills that are needed for the state benchmark tests (Newmann, Secada, & Wehlage, 1995). It also diminishes the quality of teaching and student engagement (Scales & Taccogna, 2000).

Highly qualified teachers, based on the NCLB Act, were not those who had teaching experience in a subject field but those who had at least a bachelor’s degree, were accredited by the State Department of Education, and were able to demonstrate subject matter competence in the core subject matter taught (Johnson and Hanegan, 2006). Moreover, teachers were categorized based on teaching elementary or high school levels. The middle school teachers were needed to meet either elementary or high school standards based on their school’s requirements to be considered highly qualified under the NCLB act (Johnson and Hanegan, 2006).

According to the National Science Teachers Association (NSTA) 2012 report, misguided science education in NCLB-directed programs has resulted in students not properly absorbing the needed fundamentals and the required skills to learn content-heavy high school science courses. Additionally, schools’ focus on teaching good citizens to be good problem solvers and creative thinkers shifted to the teachers’ evaluations and standardized test scores (National Science Teachers Association, 2012).

Every Student Succeeds Act

During President Obama’s administration, NCLB was replaced with the Every Student Succeeds Act (ESSA) in 2015. The purpose of this Act was to replace and modify NCLB to improve the educational system. ESSA replaced some old rules but kept the standardized testing requirements from NCLB. In ESSA, the standardized tests’ evaluation and accountability system moved from the federal level to the state governments (Pelsue,
2017); each state had the flexibility to choose its own goals and plan for students' educational success. Both NCLB and ESSA reauthorized the Elementary and Secondary Act of 1965 (U.S. Department of Education, 2017).

**The Next Generation Science Standards**

The Next Generation Science Standards (NGSS) is one of the recent developments in science education (Next Generation Science Standards Lead States, 2013). The NGSS has been initiated by the states and not the federal government to improve science education for all students (Next Generation Science Standards Lead States, 2013). It has also received significant support from the American Association for the Advancement of Science (AAAS), National Research Council (NRC), and the American Association for the Advancement of Science (AAAS) to develop, review, and expand the adaption and implementation of the NGSS by other states that have not yet embraced it (Next Generation Science Standards Lead States, 2013). Thus far, twenty states and the District of Columbia have adopted their standards based on the K-12 science education framework’s recommendations designed by NGSS. According to the New Mexico Secretary Designate of Education, New Mexico also adopted NGSS standards in 2017. The hope is that integrating new standards with K-12 education will make more students intrigued in science and continue their careers in the scientific fields to secure U.S. social and economic development and maintain democracy across the nation for all the citizens. Therefore, emphasizing the development of successful math and science education is key to achieving these objectives. “[T]he nation’s capacity to innovate for economic growth and the ability of American workers to thrive in the modern workforce depend on a broad foundation of math and science learning” (Carnegie Corporation of New York, 2009, p. 1). This mission is also to maintain a thriving democracy
and the promise of social mobility at the core of the American dream.

Furthermore, in Rhoton’s (2018) foreword, Bruce Alberts describes that the current U.S. election cycle has made researchers strikingly aware of the potential risks that society faces. For example, a large population now does not accept findings that have been arrived at via scientific consensus. The current threat to democracies is a widespread distrust of experts and a preference for “alternative facts” (Rhoton, 2018, p. ix). This realization raises the stakes for our education systems: We desperately need to provide a much-improved science education for future generations that empowers adults to act as successful problem solvers and make wise choices for themselves, their families, and their country (Rhoton, 2018). A clear goal for science education is no longer producing more scientists but producing citizens who can “think like a scientist” (Rhoton, 2018, p. ix). These citizens should be able to make the best decisions in their lives based on evidence and logic rather than on emotions and magic thoughts. This is a wise technique that allows pupils to practice critical thinking and act scientifically in different situations, using various skills to prepare for adulthood. Yet, we might not know what skills and abilities are required for future living. Everything is rapidly changing, providing an educational environment that encourages critical thinking, creativity, and independence to empower the students to act more effectively and efficiently in their lives. Individuals might encounter many challenges in their life, but their past experiences and practices allow them to think more critically and make the best decisions more independently. Therefore, K-12 science teachers need to improve their teaching goals and pedagogies to address this goal. Teachers need to consider the constant and complex changes in contemporary society to develop pedagogical approaches that support and prepare students
to be practical and rational thinkers. According to Fullan (2007), “educational change depends on what teachers do and think—it is as simple and as complex as that” (p. 129).

The Next Generation Science Standards (NGSS) were developed and released by National Research Council (NRC) in 2012 (NGSS Lead States, 2013) to enhance the new science educational goal (Rhoton, 2018). The standards are arranged in a table with three main sections, including performance expectations, the foundation boxes, and the connection boxes (NGSS Lead States, 2013). There are different standards for every grade level, which refers to kindergarten through fifth grade, and grade band standards for middle school (sixth through eighth grade), and ninth through twelfth in high school (Next Generation Science Standards Lead States, 2013). The NGSS design is created to allow the students to use their pre-existing skills and knowledge to revise and build on more knowledge throughout their school years. Based on the new educational recommendations, educators need to recognize that the NGSS is a collection of principles and does not prescribe or support a specific curriculum (National Science Teachers Association, 2013). A primary objective of the NGSS and a requirement for its successful implementation is for students to build and apply ideas in a cohesive manner or progression during each year or course (National Science Teachers Association, 2013). Providing such an opportunity for students to think scientifically in their daily lives needs to prepare teachers and familiarize them with NGSS student performance expectations (Appendix C). For delivering quality NGSS based instruction, “[t]eachers need a thorough understanding of the disciplinary core ideas and practices they are expected to teach, how students learn them, and the range of instructional strategies that can support student learning” (National Science Teachers Association, 2013, p. 2). Ongoing professional development is needed to enable experienced teachers to make a significant shift from
teaching facts and the way that they have taught in college to the new science education that seeks NGSS-based learning through new strategies, materials, and assessments (National Science Teachers Association, 2013; Rhoton, 2018).

A modification in the knowledge and competencies of the content will need to be made for many teachers. According to National Science Teachers Association (2013), to support the implementation of NGSS, teachers must demonstrate the ability to

- master the science and engineering content in the NGSS at the grade level/band they teach;
- integrate the three dimensions of science and engineering practices, disciplinary core ideas, and crosscutting concepts in instruction and classroom assessment, instead of teaching them separately;
- organize, maintain, and use instructional materials in student investigations in a safe and effective manner;
- facilitate appropriate and effective discourse and argumentation with and among students;
- integrate engineering design concepts into science instruction;
- collaborate with mathematics and English language arts teachers to capitalize on the recommendations in the NGSS connection to Common Core State Standards;
- assess and monitor student movement along the progressions within a year or course and over the entire K–12 experience; and
• provide support and remediation for those students falling behind in their achievement of the expected progression and additional challenges for students who are ready to move ahead in the progression (p. 3).

Besides the challenges associated with the implementation of the new science standards, teachers also need to know how to evaluate the instructional materials associated with NGSS content (National Science Teachers Association, 2013). They need to know how to differentiate instruction so as to properly support and challenge all the students, including those who are struggling and those who are excelling. Moreover, teachers need to know how to maintain an environment in the classroom, enhancing the affective element of learning, such as technology (National Science Teachers Association, 2013). Therefore, considerable time is needed for teachers’ preparation, NGSS implementation, and teachers’ growth evaluation. This dedicated time is necessary before full implementation to maximize awareness and understanding among stakeholders and help teachers plan entirely based on NGSS (National Science Teachers Association, 2013).

The first step for educators to start is to understand the NGSS framework for K-12 science education (National Science Teachers Association, 2013). Including Practices that reflect the means via which scientists and engineers engage in systematic design practice, Crosscutting Concepts that connect understanding throughout these disciplines, Core Ideas of life sciences, physical sciences, Earth and space sciences, and engineering technology (National Research Council, 2012). These three dimensions are distinct and equally essential for learning science. They are all combined to form each baseline-or success expectation-and each dimension interacts with the other two to help students develop a consistent understanding of science over time (Sarna et al., 2013). Hence, the framework document
needs to be fully understood and fundamentally be used for the standards (Next Generation Science Standards Lead States, 2013; National Science Teachers Association, 2013). More specifically, these three dimensions need to weave through every part of science education, especially in the curriculum, instruction, and assessment, which are the main components of teacher preparation to improve students’ performance. The following is an overview of the three dimensions described in the Framework (National Research Council, 2012).

**Science and Engineering Practices.** Science and Engineering Practices of the Framework is meant to provide an opportunity for K-12 students to solve real-world problems using science, mathematics, and engineering concepts (Brophy et al., 2008; Roehring et al., 2012). In this design, students are expected to develop problem-solving skills, communication, and teamwork skills, especially collaboration, a frequently utilized instructional procedure to engage students in solving open-ended problems usually situated in real-world contexts (Brophy et al., 2008; Roehring et al., 2012). The framework uses the term “practices” instead of “science processes” or “inquiry” skills to show the importance of both skills and knowledge for each act. According to the National Research Council (2012), “[W]e use the term “practices” instead of a term such as “skills” to emphasize that engaging in scientific investigation requires not only skill but also the knowledge that is specific to each practice. (National Research Council, 2012, p. 30).

There are eight practices in the framework, as outlined by the Next Generation Science Standards Lead States (2013). These acts or practices are identified as essential components of science and engineering for all students to learn at each grade level;

1. Asking questions (for science) and defining problems (for 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 (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information (p. 1)

Each of the above practices can be scaled to an appropriate learning and grade level/band from kindergarten to K-12 (Next Generation Science Standards Lead States, 2013). Kindergarten students start with less complex activities to develop a simple representative model, while high school students need more analytical and multilayered activities as they progress. In doing so, engaging in science maximizes students' interest and curiosity and allows them to learn more meaningfully than just memorizing the contents. One way to ensure that a practice is being utilized for science and engineering is to check each activity's goal. For science practice, the goal is for the students to respond to a question, while for engineering, students need to define and then solve a problem for the same activity (Next Generation Science Standards Lead States, 2013).

Furthermore, Science and Engineering Practices are a core part of the science curriculum to make students interested in STEM. Hopefully, learning science through these practices will raise the number of students pursuing STEM fields (Next Generation Science Standards Lead States, 2013) to fill future technology-based jobs (National Research Council, 2009). According to the Carnegie Foundation commission of distinguished researchers and public and private leaders, “[t]he nation’s capacity to innovate for economic growth and the ability of American workers to thrive in the global economy depend on a
broad foundation of math and science learning, as do our hopes for preserving a vibrant democracy and the promise of social mobility for young people that lie at the heart of the American dream” (Carnegie Corporation, 2009, p. iiiv).

**Crosscutting Concepts.** Crosscutting concepts is the second dimension of the NGSS framework. Students can expand their comprehension of the disciplinary key ideas and build a coherent and scientifically-based view of the world through this dimension. They can also make sense of phenomena across the science disciplines (National Research Council, 2012). “Crosscutting concepts have value because they provide students with connections and intellectual tools that are related across the differing areas of disciplinary content and can enrich their application of practices and their understanding of core ideas” (National Research Council, 2012, p. 233). There are seven Cross-cutting concepts as follows.

1. **Patterns:** Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.

2. **Cause and Effect:** Mechanism and explanation. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.

3. **Scale, Proportion, and Quantity:** In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system’s structure or performance.
4. **Systems and System Models**: Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.

5. **Energy and Matter**: Flows, cycles, and conservation. Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems’ possibilities and limitations.

6. **Structure and function**: The way in which an object or living thing is shaped and its substructure determines many of its properties and functions.

7. **Stability and Change**: For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study (National Research Council, 2012, p. 84).

**Disciplinary Core Ideas.** The Disciplinary Core Ideas outlined in the NGSS Framework are the elemental thoughts that are essential for understanding a given science discipline. The Core Ideas provide a key apparatus for understanding or examining complex thoughts and talking about issues related to societal or individual concerns. They can also be instructed over different grade levels at dynamic profundity levels and multifaceted nature (National Research Council, 2012). This dimension has four domains: Physical Science, Life Science, Earth and Space Science, and Engineering. Every one of the center's thoughts delineated in these four spaces expands on one another as students learn through grade levels and grade bands. These progressions of thought complexity across grade levels are described as a learning progression. Much of the time, an individual lesson or unit alone doesn't give adequate guidance for students to have the option to effectively and comprehend entirely
Disciplinary Core Ideas. Nevertheless, all lessons and units should work toward students’ ability to meet the assigned Disciplinary Core Ideas for the particular grade level (National Research Council, 2012). While the NGSS does not provide a defined curriculum, educators can use the above information as a guideline to plan, teach, and assess K-12 science units (Next Generation Science Standards Lead States, 2013). In addition, teachers’ personal, cultural, and organizational factors that vary among K-12 educators add to educational reform's conflicting execution (Bidwell, 2001; Cuban, 1993, as cited in Bowden, 2018). Therefore, the teacher’s thinking and action must change as the connection between these relevant elements affects the teacher’s thinking and action.

The Role of Immigrants in U.S. Science Education

In general, the United States has welcomed immigrants who have expertise in a variety of science fields. Historically, the U.S. has provided a warm welcome to scientists and mathematicians from other countries to continue their research and expertise in an open, free, and diverse environment while respecting different religions and political ideologies (Bosco, 2017). Joseph Priestley was among the first British chemist immigrants who left his homeland in 1794 due to political issues (Bosco, 2017, p. 23). Albert Einstein is another immigrant Physicist who left his homeland, Germany, in 1933 due to Nazi persecution (Calaprice et al., 2015). Receiving a large number of such foreign-born scientists has contributed significantly to the U.S. ability to become advanced in technology and the economy. According to Bosco (2017), “America's immigrant scientists have played important roles in making the United States a world leader” (p. 6). One-third of the scientists who won the Noble Prizes in the United States were foreign-born scientists (National Research Council, 2007). According to the Department of Homeland Security website
(2018), "there were 1.2 million F and M international students in the United States in March 2018" (para. 2). However, this number is declining due to the recent U.S. political climate and enforcement of some restricted immigration laws (Department of Homeland Security, 2018). Thus, in order to fill an unavoidable gap due to such a decline in immigrant scientists and technologists, it is necessary to design and apply teaching pedagogies implemented by effective teachers to raise the number of skilled domestic students. This will remain an ongoing challenge and must be considered because it will determine U.S. science and technology's competitiveness on the global stage.

**Physical Sciences and Student Learning in the USA**

Today the issues associated with air and water pollution, nuclear disarmament, waste disposal, inexpensive sources of energy, and so on need to be resolved promptly; otherwise, these problems will devastate human life (Puri, 1969). Understanding and prioritizing the issues requires a basic comprehension of science and its impact on society on a larger scale (Puri, 1969). K-12 Middle School Physical Science curriculum introduces “the fundamentals of physics and chemistry; students explore the amazing universe we live in, including motion, energy, the nature of matter and atoms, how chemicals mix and react, and the forces that hold the universe together” (New Mexico Public Education Department, 2009, p. 511). Krajcik (2013) also believes that “[s]upporting students in learning integrated understanding is critical as it allows learners to solve real-world problems and to further develop understanding” (p. 14). Hence, concepts in physical sciences need to be taught with a deliberate, effective, and efficient teaching pedagogy to maximize learning and understanding of the essential aspects in a timely fashion.
The National Council Educational Research and Training (NCERT) (2013) defines learning as a process that “occurs through various exposures and not necessarily through a common, singular exposure predicted by the teacher. It is essentially a participative process in which learner constructs her knowledge in her own ways, through absorption, interaction, observation and reflection” (p. 103). Core ideas are also the building blocks of science education (Stevens, Sutherland, and Krajcik, 2009). The core ideas in physical sciences provide a better understanding of such essential questions as “How can we make new materials?” and “How can information be shipped around wirelessly” (Krajcik, 2013, p. 14).

**Obstacles in Teaching & Learning Science**

Sometimes, the apparent difficulties in learning science become obstacles for students to develop a taste for their learning (Rohandi, 2017). Students as a learner, teachers, or educational institutions as the deliverer of the curriculum, and science as a body of knowledge, all play a role in the perceived difficulties students have learning scientific concepts effectively (Logan, 1981). Many other subfactors in each category might cause or enhance such learning difficulties. For example, lack of ability and poor background, weak motivation, bad study habits, and slow cognitive development can play a role in student problems. Poor teaching strategies, ignoring students’ background knowledge, and cultural insensitivities or misunderstandings fall into the teacher problems category (Logan, 1981). Therefore, there are many avenues and opportunities for different approaches that, if revised or modified, can improve students’ learning processes. However, we need to proactively identify the principal origins of the problems for maximum and optimal outcomes.

A recent study by Rohandi (2017) examined the factors that influence students’ perception and learning (for physics). The participants were 107 students, grades 7 and 8,
from two suburban schools in Indonesia. Data were collected via questionnaires asking about their difficulties and preferences and their reasons for each question. Classroom observations were also conducted to improve the quality of the collected information regarding the teaching and learning process. The outcome of this study indicated that most of the students had difficulty solving problems, and they experienced that “Science (Physics) is difficult” (Rohandi, 2017, p. 19). Among the participants, this feeling towards the science of being difficult was more noticeable among girls than boys. This perception of difficulty also led to the majority of the students' view that the physics curriculum contents were not interesting (Rohandi, 2017). Part of the reason for this negative perception was found to be related to those activities that relied on more abstract concepts involving equations and computations. Meanwhile, students showed more interest in learning physics concepts when they appeared to be relevant to their everyday life and easier to grasp.

Regarding the student's lack of interest or a mental block, Puri (1969) believes that it forms due to the “introduction of new terminology to symbolize certain well-defined concepts. This new terminology can be considered a foreign language until the individual becomes familiar enough with it to make it a part of his established vocabulary” (p. x). The results of the study by Rohandi (2017) suggested that active learning strategies, such as hands-on activities rather than traditional teaching, enhance students’ interest and improve the learning process. The data showed that teachers' long lectures and abstract problem solving reduce the students' interest and learning (Rohandi, 2017). Therefore, to make science more interesting, exciting, and understandable for students, teachers need to use different and improved teaching strategies and implement various practical activities that elevate student engagement and responsibility in their teaching pedagogies. In addition, the
teaching method should allow students to learn how to connect concepts to the principles of science. Lastly, teachers must provide a learning environment that respects students' culture and experiences; and allows the students to construct knowledge both individually and cooperatively in groups, as recommended by Rohandi (2017).

**Effective Modern Science Education**

Many different approaches can be arranged to enhance the student learning process in the sciences. A common notion is that good science education needs to be "true to child, true to life, and true to science" (National Council Education Research and Training, 2013, p. 52). This means that science teaching and learning need to be understandable, engaging, meaningful, and enjoyable to the child. Relevant science is required in order to display connections between class activities and real-life applications. Good science education needs to prepare the students for life concerns and teach them how to preserve the environment and natural resources. Finally, students need to obtain the required scientific skills such as "observation, communication, classification, measurement, inference, and prediction" to acquire and validate scientific knowledge (National Council Education Research and Training, 2013, p. 55).

Teaching should be beyond merely the transmission of knowledge from an educator to the learners. Instead, students need to actively construct knowledge based on their own experiences (Bada & Olusegun, 2015). “Teachers are not living textbooks; students not sponges, clean slates, or empty vessels” (Morgan and Saxton, 2006, as cited in McLauchlan, 2007, p. 124). Instead, the teacher needs to act as a facilitator to coach, mentor, and help students develop an understanding based on their prior knowledge and awareness in a socially constructed environment (Bada & Olusegun, 2015). This concept also stems from
Vygotsky's sociocultural perspective. He believes that “understanding do not dislodge the previous ones but complement them” (Kouzlin et al., 2003, p. 5). Therefore, science's successful teaching and learning require a student-centered pedagogy as a constructivist classroom's central focus.

**Relevant Science**

One method to make science easy and understandable for the students is to link science education topics to real-world events pertinent in the 21st century (Ahmed Alismail and McGuire, 2015). Although individuals customize their ways to learn based on their preferences and flexibility, some factors facilitate the learning process, such as “cultural experiences, personal history, interactions with others in that culture, and the collective experiences of the group” (Stears et al., 2003, p. 110). Thus, there are many ways to construct knowledge. It would be more useful for learners when the educators provide a social learning environment along with a “culture-sensitive pedagogy” (Thomas, 1997; Stears et al., 2003, p. 111). Such a learning environment offers a safe, comfortable, and collaborative learning atmosphere that challenges the students’ prior knowledge with everyday experiences to make new ideas and extend their learning (Thomas, 1997; Stears et al., 2003). While learning about all the various cultures that students bring to our classroom may not seem feasible, listening to and recognizing their needs, desires, and experiences will provide teachers with ample knowledge to adjust their teaching strategies to support the students.

I usually teach my students topics beyond the standard science curriculum to give them a broader perspective of life. I consider them all my children, and it is important for me to see them happy and successful in the future. I provide my students with emotional
support to make sure that they value education and stay on the right path to achieve their goals. This might not be common among all the teachers, nor is it part of the curriculum, but I think it is essential to equip our current and future teachers with skillsets to engage the students more intimately.

In my view, one of the key reasons that some of our students don't like math and science is that they see them as very abstract and can't connect their future to any of the topics they learn at school. For example, students cannot see the connection between learning mathematics and developing problem-solving skills. “Of all school subjects, mathematics introduces and develops the "problem-solving" concept as a fundamental component of school learning with a strong formative effect on students” (Căprioară, 2015, p. 1). Some students think that mathematics is only necessary for those who want to become a mathematician. Therefore, teachers are responsible for establishing a teaching strategy that shows the relationship between learning different school subjects and real-life usage. Discussing various life circumstances, work requirements, facts, and possibilities in many facets of life will give them a greater understanding of school subjects' learning.

Encouraging students to consider and plan for the future may make them more logical and realistic. Moreover, they can become more prepared to face and correctly address unexpected life issues.

The students need to know the purpose of learning science; otherwise, they hardly pay attention to learning. According to Dewey (1916), “Attention means caring for a thing, in the sense of both affection and of looking out for its welfare” (p. 192). Thus, purpose-based learning seems to engage and motivate students to learn. For example, I teach science using the WebQuest website once a week. I let my students explore the internet and learn through
accessible and engaging websites, games, videos, and virtual labs. If I share some exciting facts about the topic of the day or show them how they can relate the topic of the day to their future or even to their daily lives, most of the students will do it with joy. Otherwise, they do not pay enough attention to learn, and lack of interest eventually turns their attention toward playing random games on the computers.

**Teacher-Student Relationship**

The teacher's attitude plays an essential role in the teacher-student relationship (Ryan et al., 1994). A negative mindset can deteriorate a good relationship and lessens the student's attitude toward learning. Roman (2014) stated that this deterioration is caused by the fact that “teachers cannot understand their students” (p. 827). Mutual understanding, respect, and the importance of the subject for students are key factors that establish good communication between teachers and students. A teacher can positively impact the students by providing an affective-motivational environment that leads to learning (Ryan et al., 1994).

Moreover, a positive student-teacher relationship leads to higher-level self-esteem, confidence in the future workforce, and academic performance (Ryan et al., 1994). Research by Murray & Malmgren (2005) also articulated the link between positive teacher-student relationships and academic performance reflected in students' GPA. This study also recognized that a student's motivation to learn is another factor that affects the student's academic and social performance (Murry & Malmgren, 2005).

**Student Science Identity**

Some researchers indicated that improving science identity can increase students' likelihood of entering science-related professions (Stets et al., 2017). Students’ science identity is defined as “the sense of who students are, what they believe they are capable of,
and what they want to do and become in regard to science” (Brickhouse, 2001, as cited in Aschbacher et al., 2010, p. 556). If it results in the feeling of becoming a scientist, even during the short moments in the classroom, this identity can positively impact the learning process. In this regard, Aschbacher et al. (2010) conducted qualitative research on 33 diverse high school students to identify how relationships and interactions with family, educators, and peers affect students' science aspirations, identities, and activities in different social communities. In addition, the researchers wanted to know why some middle school students who are highly interested in science decide to leave the science, engineering, and medical pipeline by the end of high school while others choose to persist. The result of this study stressed that support and high expectations from relevant people such as family, friends, teachers, and peers positively impact students' academic success, aspirations, and science identity (Aschbacher et al., 2010). Thus, providing opportunities that support the students to construct their science identities by experiencing success socially and high expectations will be obligate, motivating, and encouraging them to learn science.

**Student Motivation and Engagement**

According to Palmer (2007), motivation is one of the critical factors for quality education. To enable the students to stay continuously motivated, educators should provide an inspirational environment for them to learn. Although motivation is needed for learning science, teachers need to provide engaging activities that capture students' attention. “[M]otivating students is important—without it, teachers have no point of entry. But it is an engagement that is critical because the level of engagement over time is the vehicle through which classroom instruction influences student outcomes” (Irvin et al., 2007, p. 5). Therefore, choosing activities wisely with a broad spectrum of motivation, engagement, and
learning can encourage students to benefit from them. According to Traianou (2006), the student's initial understanding also happens through their engagements. Therefore, teachers need to be able to skillfully “ask questions that aim to interpret and clarify the problem” (p. 75). Moreover, if the teachers possess adequate scientific knowledge in their field, they can readily use Vygotsky's scaffolding techniques to guide the students to learn and solve the problems (Vygotsky, 1978).

I always try to start my classes by asking the students exciting and critical thinking questions to engage them and make them interested in learning science. For example, problems I have asked include, “why is space cold if the sun is up there? Why can we hear radio waves even though they are light waves and not sound waves? Why are X-rays and Ultraviolet waves dangerous? Why do we need to consume the right dosage of medications when we are sick? How is lightning made? And, how can you save someone from an electric current?” In most cases, the students show full attention and participate in class discussions and activities.

To keep students engaged, work with enthusiasm, and so that they will enjoy learning, Williams-Pierce (2011) identified “student, teacher, content, method/process, and environment” as essential components affecting the students’ motivation (p. 1). For example, education should be easy, enjoyable, and accessible to the students. The teacher should have sufficient skills to monitor the students’ learning and should be able to adjust the educational process based on individuals’ needs. The content needs to be accurate, exciting, timely, and relevant to the students’ needs and dreams. The teaching method should be creative, exciting, and inspiring so that it can connect the content to real-world events. Finally, the teachers need to provide a safe, helpful, and personalized environment for the students to keep them
motivated (Williams & Williams, 2011; Palmer, 2007; Debnath, 2005). Putting these principles next to each other might help the students feel accountable for their learning and support them in a constructivist classroom. Furthermore, in constructivist classrooms, teachers are mentors or facilitators, and they are not “a sage on the stage” (Singh and Yaduvanshi, 2015, p. 2). Thus, instead of transferring knowledge, educators should develop an approach that leads to active learning.

**Methods of Teaching**

Marek & Cavallo (1997) believe that inquiry-based teaching can provide a basis for the thinking process that leads to a deeper understanding of science concepts. One of the new educational approaches is inquiry-based teaching. In this method, students are needed to think and act like real scientists to explore and discover facts and relationships among variables (Pozuelos, Trave, & Canal de Leon, 2010). The research conducted by McDonald (2003) examined the effectiveness of a traditional and teacher-centered educational method versus a social-constructivist, inquiry-based approach for teaching physical science concepts. This examination indicated that there is not a significant difference in students' performance comparing these two methods. Instead, McDonald's data suggested a high level of student-student interaction, as well as improving the attitudes of students toward science through the inquiry-based teaching method as an effective method of learning (McDonald, 2003). Finally, a teaching style that encourages the students to build their knowledge via experiences, observation, documentation, analysis, and reflection is required. Hands-on activities are shown to be an effective and enjoyable method for learning science (Hodson, 1990). Hands-on activities engage the students more by providing opportunities to test their own ideas and construct their knowledge (Ewers, 2001). A study by Ateş and Eryilmaz
(2011) investigated the effect of frequent hands-on activities, including mind-on experiences, on 9th-grade students in two physics classes. This study showed that the 70 students experiencing frequent (twice a week) hands-on activities obtained a higher test score in both these physics classes than the control group, which included 60 students taught using traditional teaching methods. Although students achieved higher scores in science, their attitude toward learning science, specifically on the topic of electric circuits, did not change significantly (Ateş and Eryilmaz, 2011). Therefore, an effective teaching framework is required to improve students' academic achievement and improve students' attitudes toward learning science.

**Hands-on Activities.** Haladyna et al. (1982) propose that students' attitudes toward science can be determined via three main factors: teacher, student, and learning. Another study by Ogan-Bekiroglu & Oymak (2017) tested these variables' effect on students' attitudes toward learning physics. They used activity theory as a framework to utilize several different elements that interact with each other to evaluate the students' attitudes toward physics. Laboratory experiments and technology were the main tools teachers used in this research. The participants of the study were three groups of forty-eight 9th-grade male students. The first experimental group was instructed with technology-based teaching. The second experimental group was instructed with laboratory-based teaching. Finally, the control group was instructed with curriculum-based teaching. One teacher taught all the groups for two hours a week for a period of eight weeks. The first group used technology, including simulations, video recordings, smart boards, tablets, and z-books. The second group used hands-on science by using experiment sets.

The Physics Class Attitude Scale (PCAS), developed by Geban et al. (1994), was also
used to evaluate the students' attitudes toward physics before and after the experiment. In this method, 15 items were surveyed with a 5-point Likert scale, including topics such as liking physics, interest in physics, and physics necessity. The responses were scored between 15-75. Data were collected via quantitative methods and were analyzed by performing descriptive statistics and a t-test. The results of this study indicated that “variables such as how well students like their teachers, the science curricula, or the science classroom climate have been found to be key influences on attitudes toward science” (Ogan-Bekiroglu & Oymak, 2017, p. 75). Moreover, the students’ attitudes toward science were positively elevated by changing the instruction method. Consequently, the researchers suggested using more "laboratory-based and technology-supported instructions to promote a high-level attitude toward science, which stimulates students' learning of science" (Ogan-Bekiroglu and Oymak, 2017, p. 79).

**Project-Based Learning (PBL).** The origin of experimental learning goes back to Dewey and his publication on *Experience and Education* in 1938 (Robert, 2005). Dewey initiated the idea of “learning by doing” for education (Efstratia, 2014, p. 1257). According to Dewey (1916), education is the "reconstruction or reorganization of experience which adds to the meaning of experience, and which increases the ability to direct the course of subsequent experience" (Dewey, 1916, pp. 89-90 as cited in Cremin, 1961, p. 123). Project-based learning (PBL), which is a model that organizes learning around projects (Thomas, 2000), seems to be an effective approach for teaching science to 21st-century students (Bell, 2010). PBL is a teaching model that shifts away from traditional teaching or teacher-centered to the student-centered approach to learning. Within this model, students with various learning styles are encouraged to challenge their thinking abilities, problem-solving, and creativity skills and promote their communication skills (Bell, 2010). Many teachers have
experienced students asking them to do projects because the students had unique ideas (Bell, 2010). In this case, motivation and curiosity enable the students to develop a question and choose key elements independently or cooperatively around their ideas to build the project. However, teachers need to supervise, scaffold, and provide guidance through the process for higher and deeper learning outcomes (Bell, 2010). Such learning approaches create a constructivist learning environment within which the students construct their knowledge (Stivers, 2010).

PBL provides an opportunity for the students to reflect upon their experiences and work to make the best decision for a high-quality project outcome that leads to high-quality learning (Stivers, 2010). According to Bill (2010), "PBL is not a supplementary activity to support learning. It is the basis of the curriculum" (p. 39). The role of PBL in deep academic learning, especially in science, is supported by research. A review study by Condliffe et al. (2015) indicated that PBL has positive effects on science and social studies classes. PBL approaches have elevated students' engagement, motivation, and confidence in their capability in many cases. PBL also prepares students for higher-level thinking, problem-solving, and deeper learning. In Verma, Dickerson, & McKinney (2011) research, 60 secondary students participated in an applied shipbuilding project. The students received 144 hours of instructions and training in the field of marine engineering (physical science) for this project. Based on teachers’ opinions and students’ comments at the end of the project, the data revealed a high level of motivation and enthusiasm among the students throughout the project. Another research by Brush and Saye (2008) showed a high student engagement level in PBL classrooms. Thus, providing a deliberate PBL effort enhances students' learning, responsibility, independence, and discipline, which are the foundations of future academic
and life success (Bell, 2010). To summarize, three fundamental concepts that became PBL’s core values are “[c]hild-centered learning,” “learning by doing,” and “applying school’s teachings in the home” (Colley, 2008).

Even though both PBL and IBL approaches seem pedagogically equivalent, and both are based on minimally direct instruction, some differences originate from the nature of each method (Oğuz Ünver & Arabacioglu, 2011) that will be discussed.

**Inquiry-Based Learning** (IBL) was first used as a model of science instruction and was named the learning cycle by Robert Karplus from the University of California Berkeley in the 1950s and 1960s (Oğuz Ünver & Arabacioglu, 2014). This method was based on three major phases, including Exploration, Invention, and Application (Campbell & Fuller, 1982). Between 1960 and 1966, the educator Joseph Schwab suggested that in inquiry-based teaching methods, students needed to work in the laboratory as an inquiry before the teachers introduced the scientific concepts (National Research Council, 2000). In 1971, Marshal Herron developed a scale to evaluate the amount of inquiry in science lab experiences to engage the students and enhance their scientific concepts exploration more meaningfully (Herron, 1971).

The Exploratorium, a science museum in San Fransisco, is an example of informal learning that allows students to learn through exploration and quality questioning. This museum was developed by Frank Oppenheimer, a famous scientist, after observing the positive impact of hands-on learning on his high school students (Gunhold, 2011).

According to Banchi & Bell (2008), there are four types of student inquiry: confirmation, structured, guided, and open inquiry. Each type focuses on how much information, such as guiding questions and procedures, is given to students and how much
Inquiry through 5E Instructional Method. Today, inquiry-based teaching is more often used as a lesson plan following Bybee’s 5E Instructional Method. This method consists of five steps: Engagement, Exploration, Explanation, Elaboration, and Evaluation (Oğuz Ünver & Arabacioglu, 2011). Bybee (1997) states that “using this approach, students redefine, reorganize, elaborate, and change their initial concepts through self-reflection and interaction with their peers and their environment. Learners interpret objects and phenomena and internalize those interpretations in terms of their current conceptual understanding” (p. 176).

Engagement. Engagement is the first phase of Bybee’s 5E instructional model (Duran & Duran, 2004). In this phase, teachers need to engage students with an activity or a question to capture their attention and interest (Bybee, 2014). This phase might include asking probing questions that connect the student’s background knowledge to new ideas related to the lesson’s topic and concepts. Bybee (2004) recommends three strategies for teachers to maximize student engagement, including asking questions, posing a problem, or presenting a discrepant event. The following is an explanation of each phase.

Exploration. Students should be given opportunities to work with their peers on a “hands-on” activity during this phase without direct instruction from the instructor (Duran & Duran, 2004, p. 52). Students must observe, ask questions, investigate, test their hypotheses, and communicate in collaborative work with their peers. Teachers should act as facilitators or consultants, helping the students develop skills and concepts (Duran & Duran, 2004).

Explanation. The third phase is one of the essential parts of the 5E lesson. The explanation phase is a “mind-on” phase that is more teacher-directed (Duran & Duran, 2004, p. 52). Teachers should provide definitions and explanations using the student’s previous
experiences as a foundation for the discussion. Teachers should encourage students to share their ideas and evidence to clarify their claim and understanding of the concept before introducing scientific and technical terms (Duran & Duran, 2004).

**Elaboration.** Following an explanation phase in that students use their own words to explain their learning of a concept, the elaboration phase allows students to extend their conceptual understanding and skills by conducting new hands-on activities (Bybee 2009). This phase aims to help the students develop deeper and broader knowledge through new experiences. Integration of technology, such as web-based research or WebQuest, is recommended for this phase (Duran & Duran, 2004).

**Evaluation.** The evaluation is the final phase of the instructional model that allows students to evaluate and reflect critically on their understanding (Duran & Duran, 2004). According to Bybee (2014), teachers can use informal formative evaluations from the initial phase of the 5E model. However, the teacher's feedback on the appropriateness of students' explanations and abilities helps the students assess their understanding. It also gives teachers the ability to evaluate student progress toward achieving educational goals (Bybee, 2009).

Therefore, the IBL and PBL approaches' key difference is that while IBL is the art of questioning, challenging, and discovering an answer (Oğuz Ünver & Arabacioglu, 2014), PBL is a model that organizes project learning or exploring an answer. This is undoubtedly focused on challenging questions or problems affecting students' design, problem-solving, decision-making, or research activities (Jones et al., 1997; Marx et al., 1994). In contrast, IBL may be used to refer to different ways in which scientists research the natural world and offer hypotheses based on data from their analysis. This includes student activities to gain knowledge and appreciate scientific theories and an understanding of how scientists research
the natural world (National Research Council, 1996). Indeed, education has always been central to learning by discovery. For example, the best answers are the ones students learn for themselves rather than those they memorize from others (Schank, 1995).

**Technology-Based Learning.** The development of technology has greatly impacted individuals’ lives and education (Balkan Kiyici & Kiyici, 2007). As we live in the digital age, it is essential to understand and address 21st-century students' needs based on rapidly changing technology (Lambert & Cuper, 2008). New skills must be added or replaced with traditional skills. For example, it is less necessary for students to learn "hand accounting, using the Dewey decimal system, doing long division, doing manual square roots, and writing by hand" (Crockett et al., 2011, p. 17). Instead, students need to learn how to work with advanced calculators or computers to solve math problems. Having technology-equipped classrooms does not mean that learning will happen (Van Broekhuizen, 2016); teachers should use the provided advanced technologies for their teaching and offer more technology-based activities to the students. Prensky (2001) calls today's students “Digital Natives” and educators “Digital immigrants” (p. 1). He believes that Digital Natives think differently from older generations because they grow up with technology. Prensky (2001) stated that “our Digital Immigrant instructors, who speak an outdated language (that of the pre-digital age), are struggling to teach a population that speaks an entirely new language” (p. 2). Although technology is something new in this era, people have always experienced generational differences. They have been able to find common grounds to adjust their learning and lifestyle to modern life (Cahill & Cima, 2016). Therefore, it is required to focus on ways that facilitate this adaptation to improve education. The current school system might not be the most optimal educational system for the students; it can become more suitable for
new generations with some adjustments. Digital natives still need the old generations' experiences and values to function appropriately in their lives (Venter, 2017). Technology might be applied to most aspects of our daily lives now. However, individuals need to learn about social communication, problem-solving, manners, ethics, humanity, and many other elements that they need in their lives. According to Toffler, “[e]ducation has to be about identifying the skills, knowledge, and habits of mind that all of our students will need to be successful in their life beyond school” (Crockett et al., 2011, p. 19).

Having access to portable mobile phones allows constant access to online resources and informal learning at any time. It also allows individuals to communicate through this device via text, e-mail, and other available options. Students can benefit from mobile devices by having access to information, assignments, and due dates for their classes (Gomes & Mazilly, 2016). Thus, everybody needs to learn new skills to be able to function properly and benefit from them in the 21st century. E-learning is expanding rapidly with growing technology. Traditional education is shifting to “web-based learning, computer-based learning, virtual classrooms, and digital collaborations” (Gomes & Mazilly, 2016, p. 1). However, the quality of learning varies, and it is the individual's responsibility to balance entertainment and learning. Teachers should learn how to be more useful for the students of the 21st-century by acquiring new technology and offering more technology-based activities. The innovation of e-learning has changed the learning paradigm, and teachers should be qualified for this change. According to Prensky (2001), “today's neurobiologists and social psychologists agree that brains can and change with new input” (p. 6). Therefore, their brain will be able to process and learn by using these tools. Today, children are involved with technology more often than in the past. Their brain might understand technology better and
be more creative. Hence, instead of being only consumers, they can be prosumers. It will be beneficial if students learn how to use technology as well as how to create technology. This way, more effective and useful technology devices will be designed.

Nevertheless, students still need to practice old skills to balance human life and robotic life to accomplish the required tasks. As Raja (2014) stated, “we teach our kids to be consumers of technology, not the creator of technology” (p. 12). Prensky (2001) believes that there is a possibility that today's children think differently from the past because their brains undergo different developmental experiences. However, more research needs to be done to understand better if there are any developmental differences (Prensky, 2001). According to Raja (2014), “The kids did quickly learn to hack their iPads, so there's some hope for actual inventiveness” (p. 7). From this perspective, students' capabilities can be used for the effectiveness and growth of helpful technology and their academic growth and performance. Thus, an advantage of this approach is that it provides some learning opportunities for students to design or create technology-based activities and projects that might enhance their engagement, creativity, problem-solving, and critical thinking skills. This might also facilitate educators’ understanding of students' new skills and their educational needs to improve their teaching strategies.

Traditional skills might seem to be less useful in these advanced-technology times, but they are as crucial as technology-based skills. Students should be able to read and write about the facts and nature of science. Understanding the world is not just dependent on technology because it has many other dimensions. Students need to learn about the past, present, and future. They need to learn how scientists build on their understandings and the difficulties that they face. Not always everything is or works the way we wish. The students
need to practice critical thinking, problem-solving, learning, and operating with creativity.

According to Toffler, “the illiterate of the 21st century will not be those who cannot read and write but those who cannot learn to unlearn and relearn” (Crockett et al., 2011, p.17). Therefore, if students do not learn to adjust their learning and understanding with new information more often, they will struggle in the future. Crockett et al. (2011) also question educators whether the students are developing the required skills such as problem-solving, analytical thinking, collaboration, communication, ethics, action, and accountability under the current curriculum. Many teachers are now trained for Advancement Via Individual Determination (AVID) and are skilled in problem-solving activities that enhance student learning (Advancement Via Individual Determination, 2018).

Consequently, a variety of teacher training, even the yearly professional learning community (PLC), might facilitate the educational system (Beecher & Sweeny, 2008). Since technology is changing and increasing, individuals need to learn how to process the information, evaluate, build on their learning, and accomplish tasks toward success and high quality of life. Social communication, collaboration, accountability, tolerance, equity, and ethics need an implementation that requires face-to-face interactions. Otherwise, human life will turn into a robotic life with no humanity or emotional care with this technological shift.

**Intellectual Environment.** Personal interest plays a vital role in learning science. A study by Schiefele et al. (1992) on the role of personal interest in learning and academic achievement revealed a strong association between these variables. Furthermore, the data determined that individual interest profoundly impacted both academic and laboratory performance.

Some students cannot see a link between science lessons and science-related careers
or activities outside of school (Kadlec et al., 2007). These students usually do not understand the value of science, and therefore, they do not show any interest in participating in or learning science lessons (Alvarado, 2013). According to the National Foundation for Educational Research (NFER), some students “have difficulties in making direct links and associations between what they learn at school, and how they apply this in everyday situations” (p. 3). Vygotsky (1978) reasons that the mediation of intellectual individuals is essential for learning “Internal developmental processes that are able to operate only when the child is interacting with people in his environment and in cooperation with his peers” (p. 90). Therefore, students who live in an intellectual environment might value science more and understand science's nature more. These students not only enjoy performing science activities, but they are also motivated to learn.

**Teacher Role.** Teachers are one of the main influential factors in students' learning achievement. According to Sultana et al. (2009), "quality education requires quality teachers" (p. 62). Teachers’ responsibility for students' learning outcomes allows them to be more thoughtful and reflective about their teaching practices to facilitate learning (Poter & Brophy, 1988). Teachers’ understanding of students' pre-existing knowledge, learning styles, and backgrounds also provides insight into developing an engaging learning environment that motivates students and enhances their learning (Ko & Sammons, 2013). Thus, high-quality learning starts with the teacher and his/her influence on the students. The students need to know the purpose of learning science and its applications in their lives, which motivates them to pay attention and learn. According to Dewey (1923), “Attention means caring for a thing, in the sense of both affection and of looking out for its welfare” (p. 127). Therefore, to enhance students’ motivation to learn science, teachers must possess the
best methods and practices that enable them to know their students and their needs, framed in effective and appropriate pedagogy.

**Constructivist Teaching and Learning STEM**

The act of teaching while concentrating on the key concepts and frequent assessment of students’ understanding within a constructivist teaching pedagogy would promote adequate learning of physical sciences (National Council Education Research and Training, 2013). Constructivism builds upon Piaget's (1977) and Kelly's (1991) developmental work (Gray, 1997). Constructivism is a view of learning based on the assumption that experience is not something that the teacher can simply offer to the students. Instead, learners build knowledge through an involved, mental development process; learners are the builders and creators of meaning and understanding (Gray, 1997). As a teaching pedagogy, constructivism is defined as “meaning-making activities” in education (Paul, 2005, p. 60). Within this type of teaching pedagogy, students' viewpoints should be valued, and the students need to be able to ask questions to advance their knowledge base. As Chin & Osborne (2008) described, “[s]tudents’ questions play an important role in meaningful learning and scientific inquiry” (p. 1).

Questioning by students enables teachers to evaluate the students' prior knowledge and provides direction to the learners' thoughts to prevent misconceptions about the content that has been taught (National Council Education Research and Training, 2013). Questioning is also an effective strategy to enhance thinking skills such as critical thinking, creative thinking, and problem-solving (Cuccio-Schirripa & Steiner, 2000, p. 210). Therefore, teachers should consider students' cognitive developments and potential to adjust the learning objectives such that the students can benefit the most from the educational experience
Moreover, the teachers can play a constructive role in controlling students' questioning, which can passively encourage the students to participate in the active learning process. According to Good et al. (1987), when teachers less frequently call on some students with a sense that they are low achievers, give them insufficient time to respond, or give them the answers when they reply incorrectly, they do not promote active learning. Instead, they should be helping the learning process by scaffolding questions to get to the solution. In such a situation, the students prefer to stay passive, not participate, and not respond when called on. Therefore, teachers need to consider the following points regarding the students’ questioning to enhance students' learning of science as they are recommended by Chin and Osborne (2008):

a) direct their learning and drive knowledge construction; b) foster discussion and debate, thereby enhancing the quality of discourse and classroom talk; c) help them to self-evaluate and monitor their understanding; and d) increase their motivation and interest in a topic by arousing their epistemic curiosity (p. 3).

We always need to consider that students construct knowledge and meaning in the constructivist pedagogy based on their own experiences. “Experience is perhaps the most important step in the process of discovery of science through which each learner can be made to feel, reflect, and arrive at ideas” (National Council Education Research and Training, 2013, p. 104). Therefore, teachers are suggested to allow learners to observe actual demonstrations by conducting activities, projects, and experiments or by reflecting on experiences they have encountered in life to optimize the factors that positively affect teaching and learning physical science (National Council Education Research and Training,
Finding connections between classroom activities and real-life events allows students to gain meaningful insight into physical sciences and real-life applications. Consequently, teachers need to develop explicit objectives for science laboratories that enhance students’ cognitive development, advance scientific skills, and promote a positive attitude along with an understanding of the nature of science (National Council Education Research and Training, 2013).

Chin and Brown (2000) conducted two case studies of 8th-grade students to find the most effective strategies contributing to science's deep learning. The target participants were divided into two groups of three during the chemistry class that included hands-on activities. The instructions were carried out by the teacher presentation of topics, demonstration by chemistry graduate students, and whole-class discussions. The students worked in groups for several laboratory activities. Verbal procedures were given to the students for non-open-ended problem-solving activities. Data were collected via audio- and videotapes, interviews before and after chemistry unit instructions, field notes, and students' written work. They analyzed the data by looking at the transcripts of classroom discourse. Then they compared students' responses to the questions regarding their thinking and memorization of the instructions through the laboratory procedure with their laboratory reports. The transcribed audio- and videotaped interviews and the discourse during class activities were analyzed to evaluate students' nature of reasoning, predicting, and proper understanding of the laboratory work. This qualitative study indicated that students' answers to contextual questions led to deep thinking and reasoning. In this study, learning science happened through the construction and rearrangement of schemata as the students tried different strategies to find the missing pieces of knowledge during the thinking process. Therefore, learning occurs
when students connect new knowledge to their prior experience and construct explanations and answers to the questions that are formed in their minds during the activities designed by the teacher (Chin and Brown, 2000).

Twomey Fosnot (1989) defines constructivism based on four principles: a) learning relies on what we already know in a unique and effective way; b) new ideas happen as we adapt and modify our old thoughts; c) learning means inventing ideas rather than mechanically gathering information, and d) meaningful learning happens by rethinking old ideas and coming to new assumptions about new ideas that clash with our old ideas. Thus, an efficient, constructivist classroom consists of active, learner-centered teaching (Gray, 1997). In the following section, I will explain the characteristics of constructivist learning environments.

Curriculum study is grounded in John Dewey’s (1938) theory of experience. He maintains that education requires a design that is based on experiential theory. This theory emphasizes that teachers should consider and understand the connection between education and personal experience. Following the Deweyan view of experience Schwab (1969) used the word commonplace to frame the curriculum's complexity. He addressed four commonplaces: teacher, learner, subject matter, and milieu, as they appear in the learning experience. Clandinin and Connelly's (2000) used the term commonplace based on a Deweyan view of experience (1938), such that interaction, continuity, and condition became the commonplaces of narrative inquiry (Connelly & Clandinin, 2005; McDonald et al., 2016). The "three-dimensional space narrative structure" approach by Clandinin and Connelly (2000) consists of the three commonplaces of temporality, sociality, and place. These commonplaces are essential in describing the characteristics of experience.
Attention to experiences through these three commonplaces is what differentiates narrative inquiry from other methodologies. According to Dewey's notion of experience, the study of experiences is the study of life and education (Dewey, 1981). Therefore, Dewey’s three-dimensional approach can shape a well-structured research framework in the field of education (Wang & Geale, 2015). Moreover, Clandinin and Huber (2010) explain the three commonplaces or three components of narrative inquiry as follows:

**Temporality**

This commonplace is about transitionally in the past, present, and future of people, places, things, and events under study. “Events under study are in temporal transition” (Connelly & Clandinin, 2006, p. 479). This notion presumes that people construct and revise their stories based on their experiences over time. Thus, temporality is always present in a person's experience.

**Sociality**

This commonplace has two dimensions. For the first dimension, it is required that researchers address both personal and social conditions simultaneously. Connelly and Clandinin (2016) define the personal condition as “the feelings, hope, desires, aesthetic reactions and moral dispositions” (p. 480). By social condition, the authors refer to the conditions in which an individual's experiences and events are unfolding. Some aspects, including "cultural, social, institutional, and familial narratives," are essential factors to understand social conditions (Clandinin & Huber 2010, p. 4). The second dimension focuses on the inquiry relationship between researchers and the participants' lives.

**Place**

“[A]ll events take place someplace” (Connelly & Clandinin, 2006, p. 481). This
commonplace refers to the boundaries for sociality and temporality. According to Connelly and Clandinin (2006), “the specific concrete, physical, and topological boundaries of place where the inquiry and events take place” (pp. 408-481). Individuals construct meaning based on stories of experience that occur in a place and other stories that come after that. Thus, the place is a space or spaces where events or inquiries happen.

According to Prins (2017), a few studies have examined the effect of narrative inquiry on students' science learning. A recent study by Prins et al. (2017) examined the impact of stories on teaching science, focusing on natural selection on student engagement and learning. They used a mixed-method case study approach for this study. Narrative-based curriculum materials were also used for teaching and learning. The study selected two groups of 15-16- and 16-17-year-old high school students with very little pre-existing knowledge about natural selection. Teachers were advised to use age-appropriate language and content to teach 26 students in two classes. Within the two sessions that were one week apart, students needed to read the narrative text and answer the questionnaires. The questionnaires sought to evaluate students' capability to retain and understand information (Prins et al., 2017). Data were collected via classroom observations, audio recordings of classroom discourse, questionnaires, and individual interviews with teachers and learners. The study indicated a high engagement and learning level while reading narratives that illustrated the science concept. Although the result showed a 100% score for students telling the story and conceptualized learning, a lack of knowledge of the scientific vocabulary led to lower scores for retelling or describing the scientific facts. Overall, this study determined the effectiveness of using narrative as a teaching tool for learning school science (Prins et al., 2017). Accordingly, Zabel and Gropengiesser (2015) also found the effectiveness of using narratives
in science teaching, particularly in the evolution theory. In this study, seventh-grade students used the narrative mode to produce personal meaning by connecting their own experiences and values with scientific content. The result of this study indicated a high correlation between narrative and individual meaning-making. Zabel and Gropengiesser (2015) suggested using a story as a teaching science method to facilitate learning science and scientific concepts. Likewise, Kurth et al. (2002) found a similar result by examining elementary classroom conversations. He also specified the benefit of utilizing narrative and scientific modes on student understanding of the natural world.

**Narratives as a Tool for Learning**

According to Clandinin and Connelly (2000), narrative inquiry is “the study of experience as a story, then, is first and foremost a way of thinking about experience” (p. 477). The underlying assumption is that human beings “make sense of the world by telling stories about it” (Bruner 1996, p.130). Bruner assesses that it is essential to teach acceptable scientific argument modes in a science classroom (Bruner, 1996).

All types of stories, including novels, fictional novels, autobiographies, fairy tales, and many other types, are universal (Polkinghorne, 2007). Some of these stories are shared among people in conversation or might be used for research shared via interviews or written via request (Polkinghorne, 2007). The study of stories has also been used in various academic fields such as “literary theory, history, anthropology, drama, art, film, theology, philosophy, psychology, linguistic, education” (Connelly & Clandinin, 1990, p. 2).

Although the history of interpretation of narratives goes back to the early 300 BC, due to Aristotle's *Poetics on Greek Tragedy* (Crowther & Lauesen, 2017), researchers at the Chicago School of Sociology used narrative inquiry in the form of life histories in the early
20th century (Chase, 2005; Lal et al., 2012). Later, researchers also started to look at Narrative Inquiry from other angles. For example, understanding the social construction of reality and its process began in the 1960s (Chase, 2005). Researchers explored three main questions to analyze the narrative stories: “how” stories are told, for “whom” stories are told, and finally, “why” stories are told (Lal et al., 2012, pp 4-5). Therefore, Narrative Inquiry is a critical way of gathering stories that explain for whom, why, how, and in what culture it is constructed (Trahar, 2009). According to Riessman and Speedy (2007),

The term narrative carries many meanings and is used in a variety of ways by different disciplines, often synonymously with story [...] the narrative scholar (pays) analytic attention to how the facts got assembled that way. For whom was this story constructed, how was it made and for what purpose? What cultural discourses does it draw on—take for granted? What does it accomplish? (pp.428-429 as cited in Trahar, 2009, p. 1).

Clandinin and Connelly (2000) explained how narrative inquiry characteristics could be used as a methodology to represent and understand the experience. This methodology fits well in the field of education and teaching since it needs the collaboration of researchers and participants in a place or different places over time and social interaction in various settings. A method called inward and outward, backward, and forward of experience needs to be addressed to understand it.

By inward, we mean toward the internal condition such as feelings, hopes, aesthetic reactions, and moral dispositions. By outward, we mean toward the existential conditions that is, the environment. By backward and forward, we refer to the temporality…past, present, and future… to do research into an
experience is to experience it simultaneously in these four ways and to ask
questions pointing each way (Clandinin & Connelly, 2000, p. 50).
To Clandinin and Connelly (2000), “Narrative inquiry is a form of narrative experience. Therefore, the educational experience should be studied narratively” (p. 19). These authors also offered a profound and informative conceptual framework to make the teacher's narrative meaningful and productive for their practice (Anderson, 1997). Once this information has been revealed, the researchers can interpret the teachers' stories.

**Narrative Inquiry and Teaching Science**

Although science needs rational and non-narrative thinking, narratives still play an essential role in our minds, world, and even scientific culture (Zabel, 2015). The combination of the two elevates students' conceptual understanding of science. Thus, students need to learn how to consciously differentiate the explanations of reality in the narrative mode and the scientific mode (Zabel, 2015). For example, Bruner (1986) explains that there are two different types of knowing: the paradigmatic (scientific) mode of thought and the other is called narrative knowing. Paradigmatic ways of thinking are the prediction of reality based on experimental observations, logical analysis, and proof to explain cause and effect. The objective of such a study is either proven or disproved. In contrast to this method, in narrative knowing, the knowledge is constructed based on stories of lived experiences and the meaning that is interpreted by individuals based on the experiences over time (Bruner, 1986). Unlike quantitative research, which uses math and numbers, narrative inquiry in qualitative research is a process (Carless and Douglas, 2017). Thus, narrative knowing allows researchers to “make sense of the ambiguity and complexity often attached to human lives” (Etherington, 2007, p. 29).
Narrative inquiry in the field of science education seems to be helpful and useful for students' learning. "Narratives offer increased comprehension, interest, and engagement" (Dahlstrom, 2014, p. 13614). In this research method, stories are viewed as a way of thinking. Thus, teachers and students can interpret their own experiences to shape and reshape their understanding and enhance learning. According to Hobbs and Davis (2013), “[n]arrative provides a way of focusing on connections between the subject and the learner” (p. 11). For example, in research done by Upadhyay (2006), elementary level students built scientific knowledge about estimation and measurement by sharing their lived experiences. For example, one Asian student mentioned that her mother used her index finger to measure the required amount of water to cook rice during this study. Then teacher provided more explanation on this example to show students how they can use the length of a digit of their index finger to measure things instead of using any measuring device. By connecting this student's lived experience with science, students learned how to answer some of the high-stakes test questions.

I have also experienced a similar story in my science classroom while teaching balancing chemical equations; one of my students said that he has an easy way to share how to balance chemical equations with his classmate. He mentioned that he usually cooks at home, and he shared his own story that could have been easily applied to this science topic to understand better and solve the problems. For example, everybody in his family eats a different number of eggs each time. Obviously, if he starts with nine eggs, he will have nine fried eggs in his pan. He called each element the identification code and the little numbers next to each element (O₂) as the number of eggs each person eats. Then, he multiplied those numbers by that element on the other side of the reaction (or the pan) to balance.
The incident I just stated was a straightforward logical situation that everybody seems to be able to solve. Simultaneously, many students may have difficulty grasping the problem without suitable exposure or practice. This indicates that such examples and narratives can facilitate students’ science learning. Solving science-related problems is directly related to the apprenticeship in thinking and guided participation through individual lived experiences and narratives.

Science teachers can also change an expository text into a narrative to make science more meaningful to students;

When Galileo looked through his new telescope, he could see the surface of the moon, and so he began his first close look into space. He slept during the day in order to work and see the moon at night. Many people thought that the moon was a small ball with a light of its own. Now that Galileo had a closer look through his new telescope, we realized that the moon’s surface had mountains and valleys (Hadzigeorgiou, 2016, p. 11).

Chown (1998) also used the following narrative to teach about the origin of elements and how all the atoms in our blood are the product of a violent reaction in the old star’s interior.

The iron in your blood, the calcium in your bones, the oxygen that fills your lungs each time you take a breath—all were baked in the fiery ovens deep within stars and blown into space when those stars grew old and perished. Every one of us was, quite literally, made in heaven (p. 62).

Even though storytelling is an effective method of teaching science, it is essential to design or choose useful stories that elevate the student’s level of engagement and understanding while retaining the scientific concepts (Hadzigeorgiou, 2016).
According to Clandinin (2013), “Narrative inquiry is an approach to the study of human lives conceived as a way of honoring lived experiences as a source of important knowledge and understanding” (p. 17). Each person has lived experiences that can be shared with others and even passed on to other generations. These structured, lived, and told stories are one way that assists others in shaping their lives, communities, and even the world (Clandinin & Rosiek, 2007). Thus, students can benefit from the teacher’s narrative inquiry or study of an individual’s lived or told experiences as a story to construct knowledge.

According to Trahar (2013), using narrative inquiry enables readers to make sense of how the researchers' and the participants' connection and relevance are structured in the research context. Thus, it is essential to develop narratives within a context; otherwise, the audience might not understand the interactions and meanings that are supposed to emerge from the research. For example, one might be a teacher but not be aware of the significance of educational reforms in another country or the economic crisis in another country (Trahar, 2013). Finally, the context of research is a crucial dimension of the methodological approach (Trahar, 2013). In my opinion, narrative inquiry is a practical approach that provides students with a broader vision for science learning and understanding the world in general. Learning and understanding the value of science and its applications in daily human life personally, politically, and economically through narrative inquiry might enable students to become more accountable for their learning and more responsible as informed people in a society. However, teachers' daily classroom experiences can also provide insight into improving the teaching pedagogy that enhances students' learning.

Through narratives, real-life experiences describe life inside the three-dimensional context of “temporality, sociality and location” (Connelly and Clandinin, 2006, p. 479). It is
important to note that when we choose to relate our stories, we are gathering “knowledge from the past and not necessarily knowledge about the past” (Bochner, 2007, p. 203). Hence, Making stories from one's lived history is a process by which ordinarily we revise the past retroactively, and when we do, we are engaged in processes of languaging and describing that modify the past. What we see as true today may not have been true at the time the actions we are describing were performed. Thus, we need to resist the temptation to attribute intentions and meanings to events that they did not have at the time they were experienced (Bochner, 2007, p.203 as cited in Trahar, 2009, p. 2).

A social phycologist, Elliot Mishler, was the first person to give the idea of using narrative as a tool for teaching and developing the method of validation or trustworthiness for inquiry-based research (Lyons & LaBoskey, 2002). Avraamidou and Osborne (2009) believe that narrative inquiry is an attractive method of communicating science (as cited in Prins et al.). Chatman (1978) argues that using narrative in teaching can be used in different ways across diverse disciplines.

The narrative is basically a kind of text organization, and that organization that schema needs to be actualized: in written words, as in stories and novels; in spoken words combined with the movement of actors imitating characters against sets which imitate places, as in plays and films; in drawings; in comic strips; in dance movements, as is narrative ballet and in mime; and even in music (Chatman, 1978, pp. 117–118 as cited in Prins, 2017, p. 21).

Using narrative in teaching allows teachers to gain new knowledge and understanding of their students and how they interact with the world and aids in directing and redirecting their
teaching method to consider and address the students' ethical values and needs. This is what Dewey calls intellectual responsibility, which is necessary for engaging in reflective inquiry. In his notion, intellectually responsible educators need to consider “the consequences of a projected step, to be willing to adapt these consequences.” Otherwise, the irresponsible teachers “do not ask for the meaning of what they learn, in the sense of what difference it makes to the rest of their beliefs and their actions” (Dewey, 1938/1998, as cited in Lyons & LaBoskey, 2002, p. 15).

Naturally and quite commonly, teachers tend to share their classroom experiences and teaching knowledge with others. This sharing and communication are often done through stories (Lyons & LaBoskey, 2002). Considering that teachers are insider inquirers rather than being detached, objective observers, their narratives can be used effectively. Following Bruner's two modes of knowing, these narratives along with the logical scientific method, enable teachers to construct reality and value their students’ knowledge while influencing their practice (Lyons & LaBoskey, 2002). Furthermore, Lyons and LaBoskey (2002) contend when narratives are used as a story, this sharing allows educators to capture situated complexities of teaching and classroom practice, which may often be disorganized, ambiguous, and unpredictable to these researchers. This sharing provides awareness of "what those acting know, think, or feel" (Lyons & LaBoskey, 2002, p. 15). Mitchell (1981) also explains that “story” is “a mode of knowledge emerging from action…” (p. x, as cited in Lyons & LaBoskey, 2002). The narrative thus helps teachers to get away from themselves and interact with others so that they can hear their voices and identify the necessary ingredients for transformative learning (Lyons & LaBoskey, 2002).

*The Narrative of Reality*
According to Bruner’s point of view, “[a]n individual’s working intelligence is never “solo” (Bruner 1991, p. 3). Therefore, working in groups lets the students collaborate with others with new ideas and learn from those who might know better, and generate high-quality work that is created based on effort and new learning ideas. According to Heitmann et al. (2017), learning science is more about learning facts (p. 1). Thus, narrative teaching that can put facts in stories or examples can help with students' motivation and learning (Graesser 2009). Case studies and stories are not only extra information for the students, but they are the building blocks of understanding, learning, and remembering. “[W]e organize our experience and our memory of human happenings mainly in the form of narrative stories, excuses, myths, reasons for doing and not doing, and so on” (Bruner, 1991, p. 4). Students can perform better in science by sharing their narrative examples and stories. This would let them analyze the information and recognize the “reality” (Bruner, 1991, p. 5). Therefore, a narrative story allows the students to connect their background knowledge and learning in real-life experiences toward a broader understanding and promotes longer remembering of the science lessons.

Learning science also enables students to understand the world and their role in the world (Krajcik, 2013). Students need to understand the importance of science in society and develop the required skills to provide them with a high quality of life (Rull, 2014). However, the level of positive attitude and interest in engaging with science has declined among secondary students (European Commission, 2015). The result of research done by Osborne, Simon, and Collins (2003) has indicated that the level of interest in science significantly declines as students enter secondary school. This study also showed that, in general, students have positive attitudes toward science but not toward school science.
Conclusion

Learning science provides individuals with fundamental knowledge and insight into the world and can contribute to learning specific skills such as problem-solving and critical thinking to enhance one’s life. I believe that this self-study through action research will enable me to understand students’ experiences and the impact of the constructivist pedagogy on their learning. I mainly want to identify what elements of my teaching help engage science education students and orient them to care about their learning. Thus, action research through narrative inquiry and narrative teaching would best enable me to explore my own pedagogical practices and strategies to deeply understand the impact of such teaching on student learning and engagement. This study’s approaches and findings may also help students further their scientific knowledge and personally benefit them throughout their lives and careers. Understanding the helpful strategies that enhance students’ interest and learning could help teachers justify their teaching pedagogies and help administrators' expectations for practice.
CHAPTER III: METHODOLOGY

Purpose of the Study

Learning science enables students to understand the world and its role in the world (Krajcik, 2013). Students need to understand the importance of science in society and develop the required skills to provide them with a high quality of life (Rull, 2014). However, the level of positive attitude and interest in engaging with science has declined among secondary students (European Commission, 2015). The result of research done by Osborne, Simon, and Collins (2003) has indicated that the level of interest in science significantly declines as students enter secondary school. I was interested in understanding and investigating approaches that help students be attentive in class and interested in learning science, considering their needs and culture. “Culture is everywhere in our schools and classrooms, including in places where we least expect it. That influences everything about student learning, including how children see themselves in relation to nature” (Medin & Bang, 2013). I was hoping that this research would help me identify the teaching elements that contribute to making my science classes engaging and useful for all students regardless of their race, culture, ethnicity, language, gender, economic circumstances, and physical limitations. As a teacher-researcher, I intended to use self-study action research as it is rooted in constructivism and reflective practice. They all place practitioners within the position of being observers and learners in their classrooms (Campbell, 2013). This provides an opportunity for educators to focus more on how they teach than what they teach. Feldman et al. (2004) proposed three methodological features that would be present in self-studies:

1) Self-study will bring self-importance to the forefront,

2) The teacher educators’ experience will be a tool for research, and
3) Those engaged in self-study will be encouraged to be critical of themselves and
their positions as researchers and teacher educators.

In addition to self-study, action research requires three main components, including “Look,”
“Think,” and “Act” (Stringer, 1999, p. 18). During action research, researchers should gather
relevant data to describe the situation. Then, they need to analyze and theorize the reason for
the issue. Lastly, plan and implement effective strategies to improve the problem (Stringer,
1999). This strategy allows teachers to deal scientifically with the problem to evaluate and
enhance instead of judging it based on their views (Glickman, 1992). Action research also
enables practitioners to investigate their practice profoundly, look for what works and what
doesn’t, and systematically see the effect of educational interventions (Mills, 2000).

Self-Study and Narrative Inquiry

In 1990, Zeichner asserted that self-study was a worthy research methodology to
study one’s own pedagogy. This method allows teachers to research their own practices
instead of researching other teachers and their teaching practices (Borko et al., 2008). Self-
study also provides an opportunity for teachers’ voices to be heard and encourages them to
improve their professional development based on theory and practice (Bullough & Pinnegar,
2001; 2004). Self-study is different from reflective practice (Evans, 2002). Cole and Knowles
(2000) believe that theory is not a way to implement the practice but is embedded in practice.
That means that teachers grow in their profession based on their experiences over time.
Hence, it is the teacher’s personal responsibility to advance their professional development.
This is referred to as reflexive inquiry (Cole & Knowles, 2000).

Teaching reflects a teacher’s values, beliefs, experiences, and perspectives in such a
process. Cole and Knowles (2000) also believe in the ongoing question of a practice called a
reflective inquiry. Within this concept, the practice is under continuous examination and refinement based on “personal, pedagogical, curricular, intellectual social and ethical” work contexts (Clandinin & Rosiek, 2007, p. 11). According to Bullough and Pinnegar (2004), the difference between reflective practice and self-study is that the reflection is rooted in individuals, while self-study is rooted in communication and interaction with other people. On the other hand, “self” is defined as an “individual, institution or plan examining itself in action with the goal of examining the relation between belief (or knowledge) and practice” (Clandinin & Rosiek, 2007, p. 12). Thus, reflection can be used as a self-study tool to enhance understanding of “self,” including the learning of self, the teaching of self, and knowledge of self (Clandinin & Rosiek, 2007, p. 12). Moreover, narrative inquiry allows for studying the organized content of the experience and explains the essence of the research material produced during an inquiry (Clandinin & Connelly, 2000).

Integration of action research with self-study allows the researchers to look at their own experiences and interactions before, during, and after the project (Zeichner & Noffke, 2001). Action research is rooted in Dewey's philosophical approaches to inquiry and Thorndike's science education analysis (Zeichner & Noffke, 2001). There are several different types of action research. The majority of action research includes defining a problem, gathering baseline data, implementing a strategy, and recording and reflecting on the current actions to reconsider future actions (Kitchen & Stevens, 2004). Most action researchers have engaged in some reflection in order to make sense of their work and develop their practice. Yet it was only with the move toward emancipatory action research that a group of action researchers made self-reflective inquiry explicit (Kitchen & Stevens, 2004), such as Kemmis and McTaggart, 1988 who describes action research as
… a form of collective self-reflective enquiry undertaken by participants in social situations in order to improve the rationality and justice of their own social or educational practices, as well as their understanding of these practices and the situations in which these practices are carried out (p. 5).

Planning and conducting an action research project involve raising questions about what we are doing, why, and how we can measure our practice in terms of the principles that we hold (McNiff, 2013). Action researchers are usually interested in questions that include answers about quantity, but they are more interested in quality and how they can maintain quality by observing their own experience. They see empirical issues as rooted in wider problems related to the quality of practice (McNiff, 2013). For example, it is more appropriate to ask, “How do I make my lessons more interesting so that my students want to learn?” instead of asking, “How do I help my students concentrate?” (McNiff, 2013, p. 86).

Therefore, in doing action research, researchers need to focus on two processes. One process relates to their activity with others. The other one is about learning with others. Finally, the way we collaborate with others to improve our learning affects the way we shape our acts (McNiff, 2013).

To reiterate the goals of the current study, I was willing to answer the research questions based on the following objectives.

1. To identify effective elements within constructivist pedagogies in a physical science classroom to maximize students' scientific thinking, learning processes, and interest toward science-related fields.

2. To design and implement meaningful constructivist science teaching focused on the Next Generation Science Standards (NGSS)
Research Questions

1. How can inquiry-based pedagogies influence secondary education students' problem-solving, concept development, and concept application skills in the science classroom?

2. What elements of inquiry-based teaching influence student engagement for science learning?

3. What role can teacher narratives play in understanding scientific concepts in a physical science classroom?

4. How can inquiry-based learning influence secondary education students' science identities?

Research Design

Self-study through action research was used to investigate, understand, and reflect on the learning environment and practice to enhance teaching and learning in the classroom (Vartuli, 2017). According to Kemmis and McTaggart (1988), the Action Research Spiral/Cycle “plan” implies figuring out how taking specific actions will contribute to improvements individually or collectively. Planning data collection when the actions are scheduled was also necessary to do. Maxwell (2003) explains that action researchers can't act first because they would not have any data about whether they have been good or not unless they have prepared beforehand. Since systematic data collection is desirable in research, planning makes this collection (and analysis) easier. For the most part, the “moments” of action and observation go together (Maxwell, 2003, p. 9). As we execute the improvement plans (action), we observe (gather data). Invariably, action (which we are interested in) takes place alongside other actions; that is, action analysis is incorporated into the realities of the
social dynamics and other practices. This improves the cycle of action research but also adds to its challenge. In the background of these facts, the data are collected and analyzed for action analysis purposes. Reflections would usually take place during the action, but it is important to suspend judgment and reflection before the patterns in data become apparent. Thinking about the data involves interpreting these data, often with the aid of a conceptual framework derived from the literature (Maxwell, 2003).

**Pre- and Post-Test**

In general, in this research, 8th-grade student participants took pre-and post-proficiency tests on the unit of forces and motion. For these tests, besides the multiple-choice and short answer questions, students needed to write either a scientific term for a scientific word or write the definition of each scientific term using the scientific language. Students' responses were examined qualitatively to assess their learning. I also looked for the language and narratives that were used to teach those terms.

**NGSS Engineering Design Hands-on Activity through 5E Lesson Plans**

Furthermore, all the students participated in a group project that required them to build and print a small 3D model of a racing car through the Tinkercad website for a unit focused on forces and interactions. Students will learn the unit of forces and interaction based on the following NGSS performance expectations through 5E lesson plans.

**MS. Forces and Interactions**

**MS-PS2-1.** Apply Newton’s Third Law to design a solution to a problem involving the motion of two colliding objects.

**MS-PS2-2.** Plan an investigation to provide evidence that the change in an object’s motion depends on the sum of the forces on the object and the mass of the object.
**MS-PS2-5.** Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

**MS-ETS1 Engineering Design**

**MS-ETS1-1.** 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-ETS1-2.** Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

**MS-ETS1-3.** Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each design that can be combined into a new solution to better meet the criteria for success.

**MS-ETS1-4.** 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. For example, they should design a car considering the factors affecting its speed, distance, and crash durability. The vehicles should also travel in a straight line. Students should identify any problems with their design and propose solutions to improve their car projects.

To shift from traditional teaching to NGSS, students followed the engineering design process to find the best solution for their car project. In such a process, they needed to challenge their literacy, critical thinking, problem-solving, and creativity rather than making testable explanations and predictions of a natural phenomenon. Figure 1 represents the
differences between the scientific method and the engineering design process (Science Buddies, 2021).

1. Mass, weight, balanced and unbalanced forces.
2. Friction, types of friction, how to oppose friction.
3. Motion, speed, velocity, distance, and displacement.
4. Momentum and acceleration.

Figure 1: Comparing the Scientific Method to the Engineering Design Method
In addition, for each NGSS 5E lesson plan, students participated in some hands-on activities. Pictures and real-life examples were shared during each lesson. The teacher also used the questioning technique to connect students’ background knowledge to the day’s lesson to enhance students’ growing understanding and model scientific thinking. Figures 2-6 represent a sample 5E Inquiry-Based lesson plan I used to teach Newton’s first law of motion/inertia during this unit to allow students to learn through engagement and exploration. According to Bybee (1997), “using this approach, students redefine, reorganize, elaborate, and change their initial concepts through self-reflection and interaction with their peers and their environment. Learners interpret objects and phenomena and internalize those interpretations in terms of their current conceptual understanding” (p. 176).

The 5E model consists of five learning cycles based on cognitive psychology, constructivist-learning theory, and best practices in STEM instruction, including Engage, Explore, Explain, Elaborate, and Evaluate (Bybee and Landes 1990). As shown in Figure 2, I used cooperative learning, flexible grouping, technology, and hands-on activities to maximize students’ interest and engagement in the 5E lesson plan. The lesson was also designed based on NGSS dimensions (Figure 3-4).

I started the lesson by asking engaging questions and showing engaging pictures and videos to capture their interest and connect their pre-existing knowledge to the day's lesson. Then, the students did hands-on activities to explore the concepts and skills to enhance their learning and explain what they had learned based on their experiences (Figure 5). Next, the students were expected to extend their knowledge by thinking, discussing, and applying their new understanding and skills about inertia and factors affecting inertia, such as mass, on the
3D car project. Finally, students evaluated their learning by answering the essential question of the day (Figure 6).

Figure 2: 5E Inquiry-Based Lesson Plan-Description
**Disciplinary Core Ideas**

**PS2.A. Forces and Motion**
- For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton’s third law) (MS-PS2-2).
- The motion of an object is determined by the sum of the forces acting on it. If the total force on the object is not zero, the object’s motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion (MS-PS2-2).
- All positions of objects and the directions of forces and motions must be described in an arbitrary chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be stated (MS-PS2-2).

**PS2.B. Types of Interactions**

**Crosscutting Concepts**

- Cause and Effect
- Cause and effect relationships may be used to predict phenomena in natural and designed systems (MS-PS2-5).

**Systems and System Models**
- Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy and matter flows within systems (MS-PS2-4).
Figure 4: Inquiry-Based Lesson plan-NGSS
LESSON PLAN - 5-E Model

**ENGAGE:** Opening Activity - Access Prior Learning / Stimulate Interest / Generate Questions:

1. Why do we wear seat belts? Imagine you are in a car and going to school. If the car comes to a sudden stop, what happens to your body? Why does your body go forward?
2. Imagine you are in a spaceship far from all gravitational and frictional influences. If you throw a rock, how far does it go? How fast does it go? (Newton’s first law of motion describes inertia. According to this law, an object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force.)
3. If objects with different masses are thrown as hard as possible, such as a tennis ball and a ping pong ball, which will travel a farther distance? How does mass affect the distance? Do lighter objects travel farther or heavier objects?
4. When pulling a Band-Aid off, is it better to pull it fast? (Your skin will remain at rest due to nature, and the force pulls the Band-Aid off).
5. Some other examples:
   - When you stir coffee or tea and stop, the swirling motion continues due to inertia.
   - Objects that establish orbit around the earth, such as satellites, follow their trajectory due to inertia.
   - Then, students will watch some short videos to better understand the concept of inertia.

**Tablecloth Chaos - Mythbusters for the repeat act:** https://www.youtube.com/watch?v=7PcS0DQ1g

Avoid fake videos on YouTube: Amazing Water Trick! How to Suspend Water Without a Cup! https://www.youtube.com/watch?v=7cbaM3Ef

**EXPLORE:** Lesson Description – Materials Needed / Probable / Clarifying Questions:
Students will check the following websites and do at least four of the activities. They need to show how to do the activity through the camera and submit a picture of their work on GC for a grade.

- Inertia Beads - Sikh Science! #155: https://www.youtube.com/watch?v=3g3XVXa26Q
- Egg Drop Inertia Challenge - Cool Science Trick: https://www.youtube.com/watch?v=9pScaXK8H0A
- The Coin Drop - Sikh Science! #150: https://www.youtube.com/watch?v=mo8WvU8K

**Station 1:** Change For A Dollar - Newton’s Laws of Motion Lab: https://www.youtube.com/watch?v=4N1QfWZ08JA&download=103
- Collection of Inertia Demonstrations: https://www.youtube.com/watch?v=6kSOdP2nL
- Spinning Eggs - Science Experiment: https://www.youtube.com/watch?v=3eoer3Z1CMS

**Inertia Tower:** https://www.perksinlearning.com/accessibility-science-activities/inertia-tower

Then students need to answer the conceptual questions related to the lesson of the day and submit on GC for a grade.

**Example of a conceptual question:** Give an example of an object resisting a change in motion.

**EXPLAIN:** Concepts Explained and Vocabulary Defined:

- Students need to explain inertia (Newton’s First Law): The velocity of an object will remain constant unless a net force acts on it.
  - Inertia is the tendency of objects to resist any change in motion in terms of both speed and direction.
  - If an object is moving, it will continue moving with a constant velocity (in a straight line and with a constant speed) unless a net force acts on it.
  - If an object is at rest, it will stay at rest unless a net force acts on it.
  - Inertia is a property of the object; it is not a force.
  - The motion of an object is affected by the object’s inertia.
  - The amount of inertia that an object has is dependent on the object’s mass. The more mass an object has the more inertia it has.
  - If an object has a large amount of inertia (due to a large mass) it will be hard to:
    - slow it down or speed it up if it is moving.
    - make it start moving if it is at rest.
    - make it change direction.
**Figure 6: 5E Inquiry-Based Lesson plan—Elaborate and Evaluate**

<table>
<thead>
<tr>
<th>Scientific Vocabulary of the Day:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inertia: The tendency of an object to remain at rest or remain in motion.</td>
</tr>
<tr>
<td>Newton's First Law of Motion: An object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction unless acted on by an unbalanced force.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELABORATE: Applications and Extensions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>The teacher will ask students to think about using this information to build their 3D car project. If they would like to change their prediction and explain why and how they would change it. As they conduct the investigation, the teacher will ask questions to extend their thinking: How is your initial idea about motion changing? How would you maximize the speed of the car when designing your car project? Students need to write their prediction, observation, and their new learning in their science electronic journal.</td>
</tr>
<tr>
<td>If students do not finish the explore, hands-on activity, or the worksheet of the day, they can finish them as homework and then submit on GC for a grade.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EVALUATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formative Monitoring (Questioning/Discussion):</td>
</tr>
<tr>
<td>Students need to answer the day's essential questions as an exit ticket on the jambord before they leave. Depending on how much of the class time left, the teacher will post the exit ticket questions or some questions related to the scientific word definitions on the Jambord. Students can choose an elaboration strategy as an exit ticket to share their learning about the topic or a word on jambords before they leave the class;</td>
</tr>
<tr>
<td>Give an example of the word. Give a non-example of the word. Create clues about attributes of the word; students guess. Create a question about the word. Create a simile or metaphor using the word. Use the word in a different way from the original text. Give synonyms for the word. Give antonyms for the word. Create a short story together using the words. Draw a quick picture or symbol of the word. Explain how the word relates to your life. Give additional information about the word (more facts). Paraphrase what the word means. Create a different sentence for the word. Explain how this word relates to the world currently.</td>
</tr>
<tr>
<td>I might also ask one of the following questions as the exit ticket;</td>
</tr>
<tr>
<td>What was the most important idea in today's lesson?</td>
</tr>
<tr>
<td>What were personal connections made in today's lesson?</td>
</tr>
<tr>
<td>Write three things you learned.</td>
</tr>
<tr>
<td>Create a mind map of today's learning.</td>
</tr>
<tr>
<td>Things I Learned Today __________ Things I Found Interesting __________ Question I Still Have __________</td>
</tr>
<tr>
<td>Students need to show understanding on the following information:</td>
</tr>
<tr>
<td>Essential questions: What is Newton's First Law? How does mass relate to inertia? What is an everyday example of Newton's first law?</td>
</tr>
<tr>
<td>The quality of student's answers on the jambord will also be used as a formative assessment.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Summative Assessment (Quiz / Project / Report):</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students will take a test at the end of the unit.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elaborate Further / Reflect: Enrichment:</th>
</tr>
</thead>
<tbody>
<tr>
<td>If students do not finish all the explore, hands-on activities, they can do it later and share a picture of their experiment with me on GC for a grade. They can also do it after the class or during my office hours.</td>
</tr>
<tr>
<td>Students are recommended to watch this video: Misconceptions about falling Objects <a href="https://www.youtube.com/watch?v=5hB7FjD35C8&amp;feature=youtu.be">https://www.youtube.com/watch?v=5hB7FjD35C8&amp;feature=youtu.be</a></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Materials Required for This Lesson/Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>It depends on the hands-on activity that students will be choosing. In general, they need a raw egg, hard-boiled egg, index card, empty toilet paper roll, string, pie pen or a hard plastic plate, paper, styrofoam, or plastic cups, coins, glass bottle, beads neckless, empty glass.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="https://www.youtube.com/watch?v=6v6y7DZECk8">https://www.youtube.com/watch?v=6v6y7DZECk8</a></td>
</tr>
<tr>
<td><a href="https://www.youtube.com/watch?v=8SyK8S0K0qI">https://www.youtube.com/watch?v=8SyK8S0K0qI</a></td>
</tr>
<tr>
<td>Inertia Beads - Sick Science! #153 - YouTube <a href="https://www.youtube.com/watch?v=6v6y7DZECk8">https://www.youtube.com/watch?v=6v6y7DZECk8</a></td>
</tr>
</tbody>
</table>
Narratives and Real-Life Scientific Examples

The students learned the scientific language and terminology using narratives and real-life examples. In addition, the teacher used life lessons to teach the importance of science and prepare the students for their future life and career.

Welcoming and Engaging Classroom Environment

All the above teaching methods were used in a welcoming and engaging learning classroom environment. In such an environment, the teacher creates a positive student-teacher relationship by greeting students and using professional, supportive, and motivational language to communicate with the students. As the primary goal of teaching was student learning, the teacher used consistent positive behavior throughout the school year to show her care.

Finally, for this research, I reported data based on the student's gender identity as being male, female, or other and pseudonyms for each child to protect their identities. This self-study action research took approximately two months in the 2020-2021 school year. However, more online sample work from the students throughout the school year was collected to support preliminary data analysis. Data was collected vis-à-vis student interviews and surveys, pre-and post-tests, videotapes, student work, student projects, student artifacts, and student grades.

Qualitative Method

This qualitative study used action research as practitioner inquiry (Boquet et al., 2015). The teacher also worked as a researcher to study his/her own practice and systematically reflect on it (McNiff, 1986). Moreover, the teacher explored the constructivist pedagogy's specific components that enhance students’ critical thinking, problem-solving
abilities, interests, and learning about physical science. Action research is a method of understanding inquiry in which the researcher creates an intricate, holistic image, analyzes terms, presents detailed views of informants, and conducts the analysis in a natural setting (Creswell, 1998). Although action research is rooted in Dewey’s idea of inquiry and Thorndike’s scientific study of education (Zeichner & Noffke, 2001), action research was developed by Kurt Lewin and his colleagues as a collective problem-solving cycle for improving organizations in the 1940s and 50s (Lewin 1947, 1948; Corey 1953). Action research became integrated into teacher education programs based on Stenhouse’s idea in the 1980s (Samaras, 2010). Having middle school students serve as the participants for this qualitative study made it necessary to collect multiple data to better analyze responses and explanations (Victor, Ross, and Axford, 2004).

I conducted this research during the 2020-2021 school year through online and hybrid learning due to the current situation of the coronavirus outbreak. The virtual classrooms were through Google Classroom. According to Scragg (2018), Google Classroom “is an online learning management system designed for schools. It mirrors the daily paperwork, communication, and record-keeping tasks we do offline. With Google Classroom, one can share documents and resources with students, give feedback, and assign and collect work” (p. 1). The virtual classes were also private and password-protected (Scragg, 2018).

**Participants' Demographics and Selection**

According to Dworkin (2012), a vast number of publications, book chapters, and books advocate guidance and recommend a group of 5 to 50 people for qualitative research. Through convenience sampling, which is defined as identifying participants based on their accessibility to the researcher (Hess-Biber and Leavy, 2005, 2011), I selected two of my
large and diverse 8th-grade physical science classes out of the five that I teach. The administrative staff chose the overall schedule of students in each class at the beginning of the school year.

Finally, fifty-one 13-14-year-old participants were selected for this study. The participants’ demographics were as follows: among 51 students in two of my large and more diverse classes, 51% were white, 35% were Hispanic, 10% were Asian, 2% were of two or more races, and 2% were African American.

**Data Collection Methods and Procedures**

According to the district Institutional Review Board (2021),

When conducting research that involves collecting data from one’s own students, consenting some students and not others is inherently problematic. Regardless of study design, it is nearly impossible to eliminate the coercive pressure students feel to consent when asked to do so by their teacher. Therefore, with the approval of the IRB, all students from my five classes participated in all activities and produced data for the study collection plan, so consenting students were not necessary. In addition, the survey and interview data were collected anonymously, but I used data only from two of my large and diverse classes for this study.

In the following, I will explain my data collection methods in detail.

**Pre and Post-Tests**

I posted Google Docs of the pre-and post-tests on Google Classroom for students to take and submit during class time. The test had two main parts: defining the scientific terms and identifying the scientific terms for the given explanations. To prevent students from using the test's information to answer these parts, I divided the test into two sections for
students to do over two consecutive days. This also made it easier for students to take the pre-and post-tests in shorter times. Each day, they spent only about 20-30 minutes for a maximum of 4 days for pre-and post-tests. To be more accommodating for all the students, including the English Language Learning (ELL) students, they had an option of using a hard copy or just writing their answers on a piece of paper and sending a picture of it to me via Google Classroom.

Besides the students, their parents could also check their child's class activities and grades through Google Classroom and gradebook parent view. However, no one else had access to the student tests except me.

The pre and post-test questions were the same. They were related to the forces and motion unit, including speed, velocity, acceleration, distance, momentum, mass, weight, Newton's three laws of motion, inertia, friction, balance forces, and gravity. In addition, the questions were multiple-choice, short answer/definition of words or terms, and computational. Finally, the results from both pre-and post-tests were compared qualitatively during the analysis.

For the post-tests, I expected most students to show their learning of the scientific facts and concepts through stories that applied to real-life applications. For example, to teach speed and velocity, I told them to imagine being in a car and going to school with their parent. Suddenly, they see that their parent is driving faster than the posted school zone speed. I then asked them to share their answer with me and explain the school zone speed limit. By this age, almost all the students should know the range of the school zone speed is around 15-25 miles per hour. Then, I asked what the unit of miles is for? I expected the 8th graders to mention that miles are the unit for distance and hour is the unit for time. Therefore,
by sharing this real-life story and connecting it to their background knowledge, I expected them to find the formula for speed as distance divided by time. Therefore, the unit should be miles or kilometers (in the metric system) per hour.

Moreover, I asked them where they were going? Students said school. I then explained that velocity is when they drive at a certain speed to a specific place, whereas speed is how fast they go. Therefore, the only difference between speed and velocity is that velocity has a direction.

**Survey**

Students took short online survey questions via Google Forms anonymously. According to Leavy (2017), "the questions designed around each concept in the study serve to operationalize the variables, and the answers indicate whether a variable is or is not present" (p. 269). They took the surveys three times a week for three weeks after my teaching at the end of the class. The survey questions contained short-answer open-ended questions and various rating scales from the response options. Students had the right to skip any survey questions they did not want to answer.

**NGSS Inquiry-Based Project**

Students also did an online group project using the Tinkercad website in this research. Tinkercad is an online 3D modeling program that helps individuals think, create, and do a project (Stew, 2018). Using this website, students designed a model of a 3D car. Each student was assigned to do a specific job in this project. However, everyone in a group had individual access to the design of their group project to work on it at their convenience from home. Each time the students worked on their projects, they recorded their work and experiences in their online science journals. These digital journals were created in Google Docs or Google
Slides that everybody from a group could add their information to the journal each time. The teacher then printed the 3D racing cars for no charge and returned them for assembly, decorations, and testing. Finally, students shared a videotape of their car testing in their electronic journal and presented it in class. In addition, students had the option to ask the teacher to print their 3D car projects for no charge. The teacher also mailed some 3D car projects to the students during hybrid school. The 3D car project needed to meet the NGSS performance expectations as follows.

**Science and Engineering Practices**

**Asking Questions and Defining Problems.** 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).

**Planning and Carrying Out Investigations.** Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim. (MS-PS2-2).

**Developing and Using Models.** Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs. (MS-ETS1-4). Conduct an investigation and evaluate the experimental design to produce data to serve as the basis for evidence that can meet the goals of the investigation. (MS-PS2-5).

**Constructing Explanations and Designing Solutions.** Apply scientific ideas or principles to design an object, tool, process or system. (MS-PS2-1).
**Analyzing and Interpreting Data.** Analyze and interpret data to determine similarities and differences in findings. (MS-ETS1-3).

**Engaging in Argument from Evidence.** Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. (MS-ETS1-2).

**Disciplinary Core Ideas (DCIs)**

**PS2.A: Forces and Motion.** For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton’s third law). (MS-PS2-1).

The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. (MS-PS2-2).

**PS2.B: Types of Interactions.** Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object, a magnet, or a ball, respectively). (MS-PS2-5).

**ETS1.A: Defining and Delimiting Engineering Problems.** The more precisely a design task’s criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (MS-ETS1-1).
**ETS1.B: Developing Possible Solutions.** A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4). There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3). Models of all kinds are important for testing solutions. (MS-ETS1-4).

**ETS1.C: Optimizing the Design Solution.** Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the re-design process, that is, some of those characteristics may be incorporated into the new design. (MS-ETS1-3). The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (MS-ETS1-4).

**Crosscutting Concepts**

**Cause and Effect.** Cause and effect relationships may be used to predict phenomena in natural or designed systems. (MS-PS2-5).

**Systems and System Models.** Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy and matter flows within systems. (MS-PS2-1).

**Stability and Change.** Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales. (MS-PS2-2).

**Connections to Engineering.** Technology, and Applications of Science
The uses of technologies and any 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. (MSPS2-1) (MS-ETS1-1).

**Mixed Readiness Flexible Grouping**

To encourage teamwork and to maximize student responsibility, mixed readiness flexible grouping was used (Russell, 2019). Students with varying levels of knowledge and skills were grouped (Russell, 2019). Grouping students was based on pre-test scores. This allowed students to bring their skills, talents, and life experiences to the group and learn from each other. I also used students’ pre-test scores to measure their content knowledge to create groups of 3-4 people by distributing each group with high, medium, and low performing students. Then, students identified their roles in their groups and wrote them in their electronic journals for the 3D car project. According to Russell (2019), this type of grouping encourages low-performing students and English as Second Language Learners (ESL) to participate and improve their learning by getting help from more knowledgeable students. Russell (2019) also states, "When students see their peers are succeeding, they too will want to also try and succeed, making this grouping both successful and motivational" (p. 7).

**Individual Pre-and Post-Interviews through Google Forms**

Before and after finishing the car project, all members from each car project also answered the interview questions on Google Forms anonymously. The participants answered the questions within a few days. They did it during the class after finishing their classwork or anytime at their convenience after school.
The interview questions consisted of engagement, exploration, and exit questions (Eliot, 2005). The students wrote their own experiences, and the participants had enough time to think and share their thoughts. The questions were primarily open-ended (Corbin & Strauss, 2014). Students explained their ideas and experiences doing this NGSS inquiry-based activity, such as if their group members faced any difficulties during this project and how they solved it. In addition, students needed to explain what they had learned and how they designed their 3D car project to meet this activity’s required criteria. According to Britten (2006), key questions in semi-structured interviews help researchers define the areas to be explored and allow researchers to pursue an idea in response in more detail.

**Video Recording**

It is part of our school policy to record and save the video recording of the online classes and even the office hours for teachers to be safe and to be able to address any student behavioral issues if there were any. Therefore, I used recorded videos of five lectures and instructions through Google Meet for this research. In addition, students needed to share a short videotape of their car project with the class during their final 3D car presentations. They also had an option of testing their cars live during the online class if they could not videotape it beforehand, but nobody used this option. An intelligent photo editing software was available to be used to blur the faces of research-participating students to keep their student identities confidential. Still, all the students followed the rules, and we did not face such a problem.

**Student Classwork and Artifacts**

Student daily worksheets and activities were given to the students through Google Docs on Google Classroom. They were also asked to do activities using online programs
such as STEMscopes, PBS learning media, and WebQuest. Student answers were used for the assessment. The STEMscopes is a web-based program that provides comprehensive digital resources for teaching and learning (STEMscopes, 2020). The PBS learning media also has free teaching resources, including videos, lesson plans, and games aligned to state and national standards (PBS Learning Media, 2020). Students needed to use their own language to explain the answers and show their understanding of daily worksheets or lab activities. The ELL students could answer the questions on a piece of paper or in their notebooks and share a picture of it with me through Google Classroom. In addition, students shared an electronic copy of their journals, including their 2D car designs and sketches, with the teacher through email, Google Docs, or Google Classroom. Student artifacts, including any comments, emails, and cards to the teacher, were also used for this research—the above documents are saved in a folder of my password-protected email or laptop until the study is complete.

Upon completing the study, I collected student work samples, including their digital journals, artifacts, notes, and cards, for the teacher. Data were de-identified immediately after collection. The student names were concealed from the samples. These samples were used for my doctoral degree and will be used for future teaching, presentations, and publication purposes. After completing this research, all other recorded videos, audio, and class works were destroyed.

**Data Collection Procedures Chart**

In the following chart, I will show the entire data collection method for each type of data.
<table>
<thead>
<tr>
<th>Type of Data</th>
<th>Data Collection Methods/Procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher scientific narratives and real-life examples</td>
<td>Video recording, online student survey and interviews (Google Form essay responses), pre- and post-tests.</td>
</tr>
<tr>
<td>Teacher narratives about the history of science/scientists' narratives to teach science and life lessons to value science.</td>
<td>Online student surveys and interviews (Google Form essay responses)</td>
</tr>
<tr>
<td>Student understanding of the narratives by explaining them to another student or teacher</td>
<td>Video recording and student-submitted work (assignments, activities, essays, worksheets, pre-, and post-tests) related to this research through Google Classroom</td>
</tr>
<tr>
<td>Student narratives about their experiences related to the inquiry-based learning to other students</td>
<td>Video recording, student-submitted work/assignments, and pre and post-tests</td>
</tr>
<tr>
<td>Student opinion about the effectiveness of teacher's teaching pedagogies</td>
<td>Online student interview (Google Form essay responses), surveys through Google Forms, comments, email, &amp; cards to the teacher</td>
</tr>
<tr>
<td>Student qualitative learning assessment</td>
<td>Online submitted student worksheets, car project, online presentation, an online submitted journal for the project, artifacts, and online pre and post-tests.</td>
</tr>
<tr>
<td>The teacher cares about student learning</td>
<td>Video recording of the class, online student survey, emails, cards, and comments to the teacher through Google Classroom</td>
</tr>
<tr>
<td>Student opinions about their learning through NGSS-based pedagogies</td>
<td>Online student survey and interviews (Google Form essay responses)</td>
</tr>
<tr>
<td>Student-teacher relationship</td>
<td>Online student survey, interviews (Google Form essay responses), emails, comments to the teacher through Google Classroom</td>
</tr>
<tr>
<td>Student science identity and group work</td>
<td>Video recording of the class, online student survey, and interviews (Google Form essay responses).</td>
</tr>
<tr>
<td>Student interest in science</td>
<td>Student online surveys, interviews (Google Form essay responses), class works, notes, email, or comments students write to the teacher.</td>
</tr>
<tr>
<td>Student learning through hands-on work and technology</td>
<td>Video recording, online student surveys, interviews (Google Form essay responses), submitted works.</td>
</tr>
</tbody>
</table>
Participant Compensation

There was no compensation for participation in this study. The cost of printing the 3-D car project for all the students from all five classes was the teacher's responsibility. Only a few students decided to print it by themselves. The teacher also paid for shipping the 3D printed parts of the car project to the students.

Data Analysis

Thematic Analysis

In general, qualitative research allows researchers to access the participants' opinions and feelings to understand the meaning that the participants give to their experiences (Sutton & Austin, 2015). In narrative research methods, data is understood by keeping stories intact during research on complex phenomena until they create a theory that explains the phenomena (Kellam et al., 2015). According to Vaismoradi and Snelgrove (2019), thematic analysis is one of the most common qualitative research approaches. It is “[a] method for identifying, analyzing, and reporting patterns, within data” (Braun and Clarke, 2006, p. 79). Thematic analysis is highly recommended to be learned by Braun and Claekke (2006) because "it provides core skills that will be useful for conducting many other kinds of analysis" (p.78). This method of analysis aims to identify themes from interviews or the content of the interviews (Kellam et al., 2015). Developed themes will then be compared across the cases because the narrative remains untouched throughout the analysis (Kellam et al., 2015; Polkinghorne, 1995; Riessman, 2008). Unlike summarizing the data, thematic analysis interprets and makes sense of it (Maguire & Delahunt, 2017). Thematic analysis is a method, not a methodology, that leads to significant advantages and flexibility for various work in teaching and learning (Maguire & Delahunt, 2017).
Description and interpretation are the two main components of thematic analysis that allow researchers to have an analytical examination and a higher level of description to identify themes (Vaismoradi & Snelgrove, 2019). Vaismoradi and Snelgrove (2019) also define “Theme” as “the subjective meaning and cultural-contextual message of data. Codes with common points of reference, a high degree of transferability, and through which ideas can be united throughout the study phenomenon can be transformed into a theme” (P. 2). Thus, themes or patterns provide the meaning of the data. In this research, I will follow Braun and Clarke's (2006) five-step thematic analysis, including familiarization with the data, coding, searching for themes, reviewing themes, and defining and naming themes. According to Lieblich et al. (1998), there are two intersecting dimensions to narrative analysis, Categorical versus Holistic and Content versus Form. I will explain the first dimension related to this study in what follows.

**Categorical versus Holistic.** The first dimension notes that the unit of analysis is a category or the narrative as a whole. In categorical approaches to narrative analysis, all references to the selected phenomenon in one or multiple interviews need to be compared. Holistic approaches pursue the understanding of the way a particular section of the text is part of a life story, as told during one or several interviews with the same participants (Gilbert, 2008). The common use of categorical analysis is when research is concerned with an experience shared by a group of people. For example, the procedure of migration falls into this category. However, in holistic analysis, a person's significance and change in his life are explored. The impact of migration on one's identity is an example of a holistic analysis (Earthy & Cronin, 2008).

Based on these two main dimensions, Lieblich et al. (1998) proposed four distinct
approaches for qualitative analysis, including categorical analysis of content, holistic analysis of content, categorical analysis of form, and holistic analysis of form. Each of these four approaches can be used for a different type of research, for example;

*Categorical-Content.* It is used to look at separate parts of the text to find themes (e.g., content analysis; grounded theory).

*Holistic-Content.* It is used to look at the text as a whole to find themes (e.g., case studies; thematic analysis).

*Categorical-Form.* It focuses on a certain part of the research question and then does a plot analysis (e.g., types of metaphor).

*Holistic-Form.* It is used to look at plot analysis, regression, the pattern of progression.

To analyze the data in this qualitative research, I first prepared and organized the data.

To follow Braun and Clarke's (2006) five-step thematic analysis, I read and reread the data to become familiar with the content. Then for coding, I labeled the highlighted features of the data that might be relevant to answering the research questions. After coding the entire dataset, all the relevant data were saved together for further analysis. In the third step, I examined the codes to identify themes based on the previous step's information. In the fourth step, I checked and reviewed the identified themes against the dataset to determine if they provided reasonable explanations for the research questions. I separated, combined, or discarded some of the chosen themes at this stage. Finally, I generated a detailed and clear description of themes along with an informative name for each theme.
I also limited data collection to those participating in the study (Kang, 2013). For example, I collected only the essential information through surveys and activities. For any missing data, I looked at each data set individually and determined the requirements based on the specific features and the effect of the missing data on the result.

**Validity and Implications in Qualitative Research**

Validity in qualitative research, such as narrative inquiry, refers to the “appropriateness” of the tools, processes, and data (Leung, 2015). According to Polkinghorne (2007), validity is about the credibility of a statement or knowledge which is not inherent in a claim. Issues of validity are common in qualitative research. Thus, enough evidence or reasons is needed for validation (Rosch, 1978). According to Polkinghorne (2007),

The general notion of validity concerns the believability of a statement or knowledge claim... Thus, a statement or knowledge claim is not intrinsically valid; rather, its validity is a function of intersubjective judgment. A statement's validity rests on a consensus within a community of speakers. The validation process takes place in the realm of symbolic interaction, and validity judgments make use of a kind of communicative rationality that is nonrule governed (p. 4).

Researchers need to illustrate the validity of the knowledge that is claimed by justifying and using fundamental arguments based on the proposed characteristics described by Perelman (1982 as cited in Polkinghorne, 2007). These characteristics are presented in three steps: first, in the finding and analysis step, the researchers must proceed informally and should not bind their work to the formal logic of induction and deduction; second, the data presented to the audience must be logical and convincing; and third, because the results are always presented in human language, some level of ambiguity must be acknowledged in
the interpretation, justification, and arguments for the claims that are made.

In order to check the surface validity of research, it is essential to ask if the research question is valid for the desired outcome if the choice of methodology is appropriate for responding to the research question if the methodology is well structured if the sampling and data analysis are suitable for this research, and finally, if the results and conclusion are valid (Leung, 2015). Validity in self-study is also evaluated based on the understanding of the research by clarifying the data source and describing a relevant way of data collection; however, the challenge for the validity of qualitative research must begin with understanding the ontology and the epistemology of the issues to be explored (Leung, 2015). Ontology refers to the nature of reality, and epistemology refers to how researchers know what they know (Carnagahan, 2013). For example, the concept of a word might be different across disciplines due to their philosophical perspectives. That is to say, the choice of methodology needs to provide a direct pathway to detect findings in an appropriate context for validity with regard to the cultural and contextual variables (Leung, 2015).

**Risks and Ethical Protection of Participants**

There was a risk of stress, discomfort, and anxiety as students needed to work in groups and meet deadlines. There was also a risk of embarrassment if students’ group projects did not work or broke apart while testing them in our online class. Finally, those students who did not work with their close friends in a group felt a minor discomfort. Grouping students was based on varying knowledge and skills. This allowed students to bring their skills, talents, and life experiences to the group and learn from each other. The ELL students might have found discomfort and anxiety when working with other fluent English-speaking students who might read and write faster.
To keep student privacy and confidentiality, I made sure not to talk or share any information about students’ Individualized Education Plan (IEP) or 504 Plan of accommodations with anybody. As a teacher, I followed the state and APS Covid-19 health protocol to minimize any health hazards associated with this virus to protect myself and my students. IRB ethics guided this research, and I conducted this research with respect to participant dignity and privacy.

- There was little to no potential for student participants to require psychological or medical attention from the research procedures. The interview and other forms of data collection were non-invasive.

- The anonymity of all participants was maintained at all times and throughout all data collection intervals. Participants received pseudonyms at the onset of the study, and identifiers were kept in a locked cabinet away from the research site.

- Student participants were not stigmatized for participation in the study. Participants' personal information, survey responses, and interview data were not disclosed to anybody outside of the study. The confidentiality of participants was of the utmost importance throughout the study. Study location, identifying the participants' characteristics, and participant information were modified to protect the participants.
CHAPTER IV: DATA ANALYSIS AND FINDINGS

This study aimed to identify teaching strategies that empower constructivist NGSS-based principles that enhance students’ progress and engagement. This chapter focuses on my teaching pedagogy and identifying the themes across the data. Then, the sample data is shared to exemplify the ideas supporting the identified themes. This data analysis highlights student responses to the survey, pre-and-post interview questions, artifacts, recorded videos, and pre-and-post tests. It also highlights alternate results that students considered essential teaching and learning science factors following the theoretical framework.

The collected data is related to two of my large and more diverse science classes in a large metropolitan district in the southwest, including 51 students. Among all, 25 students identified themselves as boys, and 26 identified themselves as girls—however, more than 51 pseudonyms were used in this study since data were collected anonymously.

After completing a thorough data analysis, I identified themes based on thematic analysis using inductive and deductive approaches. In this method, six-step processes were followed, including familiarization, coding, generating themes, reviewing themes, defining and naming themes, and producing the report (Braun & Clarke, 2006). In addition, the deductive approach allowed me to better understand and reflect on participants’ views, opinions, knowledge, experiences, and values based on my pre-existing knowledge. Finally, to avoid missing new patterns and relationships from the data set, the inductive approach was used to generate meaning and construct a new theory (Braun et al., 2019). Similarly, other qualitative researchers, such as Osborne et al. (2003), have also used a Likert-type scale for some survey questions to provide a reliable measurement by capturing the intensity of participants’ responses in this research project.
I color-coded the data based on similar ideas, concepts, and keywords to code. Then, I began to connect the various notions and codes that I had established during the session readings of data. As a result of that approach, I identified common themes and sub-themes to reflect this research’s concepts and codes. I also double-checked the categories for the accuracy of the information and looked for discrepancies in thematic units. Finally, themes were compared to determine the hierarchy of the principals in NGSS-based constructivist teaching pedagogy. The following materials represent the common themes and sub-themes identified while reviewing each component of the constructivist pedagogy based on the NGSS.

Due to the Covid-19 pandemic, I started this project during the online school, but the school became open near the end of this research study, and it was optional for the students to attend in person. However, all data from the survey and post-interview questions were collected anonymously through Google Forms. Therefore, different pseudonyms were used for students’ various data even though they might be from the same person.

**Guiding Framework for the Constructivist NGSS-Based Pedagogy**

Based on constructivist teaching and learning theory, students should actively participate in the learning process (Elliott et al., 2000). Therefore, I constructed my constructivist NGSS-based teaching pedagogy centered on the following principles recommended by literature. The guiding framework in this study follows Piaget’s cognitive constructivism theory and Vygotsky’s sociocultural theory. Piaget and Vygotsky were two cognitive psychologists who studied mental processes, such as how people think, perceive, remember and learn (Blake & Pope, 2008). Both theorists believe that children are curious and engaged in their own learning. They also believe that children are eager to learn new
things to expand their knowledge. In the light of this view, Vygotsky (1978) emphasizes the importance of peer contact in cognitive growth, and Piaget emphasizes the schema/new understanding. In addition, Piaget believes that new concepts can be quickly learned if they attach to existing schemes (Piaget, 1978). The following are my research questions and themes identified through data analysis. I will also explain details of the principles of my teaching pedagogy while analyzing students’ data and critique the findings in the next chapter. Moreover, I changed my name in students’ responses to “the teacher” to let the readers better focus on the concepts.

**Research Questions**

1. How can inquiry-based pedagogies influence secondary education students’ problem-solving, concept development, and concept application skills in the science classroom?

2. What elements of inquiry-based teaching influence student engagement for science learning?

3. What role can teacher narratives play in understanding scientific concepts in a physical science classroom?

4. How can inquiry-based learning influence secondary education students’ science identities?
Themes and Subthemes

<table>
<thead>
<tr>
<th>Theme 1</th>
<th>Inspiring students with teacher’s narratives and real-life examples</th>
<th>which describe the impact on students’ interest and scientific concept development and understanding.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theme 2</td>
<td>Investigating phenomena and solving problems by doing science through next-generation science standards</td>
<td>clarifies how each component of NGSS allowed students to become active learners.</td>
</tr>
<tr>
<td>Subtheme For Theme 2</td>
<td>Promoting innovation and creative design while applying the content knowledge following the engineering design process is identified as the sub-theme for NGSS.</td>
<td>The creative design emphasizes the significance of technology-based and real-life, hands-on group activity in enhancing students’ engagement, science identity, problem-solving skills, and concept application through scientific literacy.</td>
</tr>
<tr>
<td>Theme 3</td>
<td>Promoting higher achievement by teacher’s friendly yet professional behavior, by developing a relationship of mutual trust</td>
<td>where the strategies used to enhance students’ academic success are inspected.</td>
</tr>
<tr>
<td>Theme 4</td>
<td>Fostering science identity</td>
<td>which highlights the importance of competence, performance, and recognition to maximize students’ confidence to develop a science identity.</td>
</tr>
</tbody>
</table>

Analysis of Constructivist NGSS-Based Teaching Pedagogy

Value Science and Comprehend Abstract Science via Narratives

In my teaching pedagogy, the students first learn what science is and why they need to know science before teaching science. According to Lander & Gates (2010), “STEM education will determine whether the United States will remain a leader among nations and whether we will be able to solve immense challenges in such areas as energy, health, environmental protection, and national security” (p.1). Furthermore, understanding the role
of science on a larger scale of the country, planet, and universe than personal benefit prepares all citizens to make better decisions for themselves, their families, and their communities and eventually strengthen the democracy and the position of the United States in STEM globally (Lander & Gates, 2010). Therefore, at the beginning of every school year, I started my science classes by asking students what science is and how science affects their daily lives. Then, I led the conversation to the point that beyond the individual benefits and understanding of the world around us, the future of the United States depends on our students’ science and technology education. Yet, unfortunately, the interest and the number of American students continuing their careers in the scientific fields are significantly declined.

The following data from student surveys show various reasons students value science. I analyzed the data and the role of teachers’ narratives as life lessons in students’ thinking about their careers, life, and the future of their country. The data indicates students value science more or less because of their personal or family perceptions.

**Personal and Family Perceptions**

Answers to the survey question asked how important it is to do well in science class? Showed that 52% of the students mentioned science as extremely important, 42% said science as quite important, and 6% said it as somewhat important. The next survey question was asked to get in-depth information and determine the reason for their answers; what is one reason the content you learn in class is particularly important to you personally? The data showed various reasons for liking, not liking, and learning science. Some wanted to learn to understand the world better; some wanted to learn to do well at school, and others wanted to help their siblings with schoolwork. For example, Jacob stated that science “helps me
understand the world that we live in,” Ali mentioned, “It helps because my little brothers are in homeschooling, and I help them a lot with science.” Navid indicated, “They aren’t important to me personally, but overall, it is for my academics and future classes.” Moreover, 66% of the participants mentioned that science is extremely or quite useful for their future because of their science-related job interests, or at least they want to keep their opportunities open. This is also evident in students’ survey responses as Ben stated, “[i]n my future, I want to be an Air Force pilot. Therefore, I need to have a good understanding of science to be able to fly the plane,” Mehyar also indicated that “I don’t know what I want to do for my job in the future, so I want to learn things to keep science jobs as a possibility.”

In addition, more than 80% of the participants rated five or higher on a Likert scale of 1-10 in response to the statement, “I need to learn Science because the U.S. should remain a leader in science and technology.” For example, in the questionnaire, Chris and Lola responded that the U.S. should stay advanced in science and technology to compete with other countries regarding the importance of science learning in the 21st century.

Chris

Science education is important because there are so many advances every year, and it is important to stay on top of things. It is important to know science in order to compete with other countries and be more knowledgeable than other people. It is also good to know things about various topics for daily life, like knowing about viruses during covid-19, to protect yourself and stay informed.

Lola
Science is really important for many reasons, health, safety, and research. We need science in our lives more than ever, because of Covid-19, our health is at risk, and we need scientists to make up a vaccine. Science is more important than ever at the current time with research, we learn and grow, and modern-day medicines from science make us healthy. Even other types of science are important, such as engineers. We need engineers to make everyday products safe and functional. We wouldn’t be where we are today without science.

Students also mentioned that science learning is important because their family values science, as seen in several cases. Nevertheless, on a scale of 1-10, related to the question asking if they are surrounded by scientists (parents, siblings, and family friends) outside of school? Only 42% rated five or higher. For example, Gracie said, “[t]he contents we are learning in class is important to me personally because my family really values science.” Duke declared that “I often use it in conversations with my friends. I also think education is really important along with my parents.”

**Using Narratives to Mobilize Student Sociocultural Knowledge**

In the above, I discussed narratives and life lessons that helped students to value science as a field of study and choose it as a career to protect the U.S. global status. On the other hand, narratives in science teaching and real-life examples were also used to help students’ engagement and science concept learning. These narratives are shown to stimulate the students' science concept development and concept application skills, as many students described that narratives and real-life examples helped them like, understand, and remember the science content knowledge. Moreover, they indicated that narratives and real-life examples enabled them to apply the scientific concepts better to build the 3D car project. For
example, students used the same narratives and real-life examples from the teacher to respond to the survey question asking, what is the formula for speed? How do you remember it based on the teacher’s teaching? Mina wrote that “the formula for speed is distance/time. I remember this because she taught us the trick of finding a real-life example. If you find a speed limit sign that says miles per hour, miles = distance, hour = time.”

Furthermore, students found it easy to learn formulas and understand them rather than memorializing them. For instance, in a survey, Lea mentioned that “I love how you demonstrate on how to get the answers right and show us how to get those answers right and I also like how you present to the class a talk about science.” Elias also believed that real-life examples are helpful for their learning because it connects to their background knowledge. He mentioned that

Something that this teacher does that I would like all my teachers to do is give us real-life scenarios of the usage of what we are learning and giving teaching us about the importance of the topic we are learning and how we can use it outside of class. For example, when learning about measuring speed, this teacher used speed limit signs to help us understand. Speed limits are something that is a part of our daily lives and I like how the teacher was able to use things we are familiar with to help us understand what we are learning.

Even outside of school, some students could see the application of science in real-life situations to enhance their concept development, retention, and interest. For example, Ariana said:

The 3D car project has made me change my opinion of myself as a student in science because I now use and notice when I am using science in the real world. For example
the other day I was pushing a cart and as it got faster in a short period of time as more
force I used to push the cart is an example of Newton’s second law of motion. I like
science more now because I understand it more in depth in the real world.

More narratives and real-life examples were also used to engage and give students a
mental hook to grasp and remember the science content during each phase of this unit. While
only some students might understand the technical language of science (Montgomery, 1996),
stories make science easy to learn and communicate. According to Schank and Berman
(2002), “for communication, memory and learning purposes, stories are likely to be richer,
more compelling, and more memorable than the abstracted points we ultimately intend to
convey or learn when we converse with others” (p. 293).

Two main sections were used in the pre and post-tests to examine students’
background knowledge and the impact of the teacher’s narratives on students’ learning. The
first section contained 26 terms related to the unit of forces and motion that students needed
to scientifically define them and six other questions that needed conceptual understanding
and calculations based on a given graph or a picture. The second part of the pre-and-post-test
given to the student on a different day consisted of the scientific definitions of the exact
words and representative pictures. Students needed to write the scientific term for each.
There was also a multiple-choice question on the test (Appendix A).

The pre-tests were worth 5 points of participation when students had answered based
on their background knowledge, and they did not have to be correct. Yet, a few students have
extensively used online resources to copy and paste the answers, and their work could not be
considered their own. Thus, I eliminated those data for analysis. In some other cases, students
completed only the pre-or post-test. Therefore, I eliminated data from those students for better comparisons between pre-and-post test results.

Besides the real-life examples, I also used narratives and put students’ names in my stories. For example, to teach about the difference between mass and weight, I asked students to show me how one would potentially walk on the moon. Students walked precariously. I asked a volunteer to use their name in my story. I picked a person’s name and told students that Pedro planned to become an astronaut and go to the moon. After taking many years of training, he is ready to go on the space shuttle, and the crew support brought him three sizes of space suits, small, medium, and large. While Pedro usually wears medium-size clothes, which one should he pick? Students said the medium size as his mass or the amount of matter in his body would not change.

After landing on the moon, Pedro checked his weight on a scale he took to the moon. Surprisingly, his weight was six times less than his weight on the Earth. While his weight was 60 kg on the Earth, the scale showed his weight as approximately 10 kg on the moon. What can be the reason? Students immediately mentioned gravity. Indeed, they figured out that weight measures how much gravity pulls on a mass or object—another “aha moment” realizing why man walks steadily on the moon. After this lesson, students asked many questions about other planets’ gravities. Students got permission to search online to determine the difference between gravity on different planets. They were interested in seeing which planet in the solar system has the highest gravity, making it impossible for humans to walk. While only about 60% knew the scientific definition for mass and weight in the pre-test, more than 90% showed they understood these two vocabularies in the post-test. Most
students also mentioned the same story to answer the post-interview question that asked about the difference between mass and weight. For example, Marzi said;

If you were on the moon, your mass wouldn’t change, you would still wear the same sized clothes. But your weight would change because of the different percentages of gravity on the moon. You will still be 6’3 on the moon if you are 6’3 on Earth, but if you are 95 pounds on Earth, you won’t be 95 pounds on the moon.

The same strategy was used for other scientific terms in this unit. The effectiveness of narratives in students’ engagement and learning is evident in their post-test responses. While only less than 50% of the students knew the answers to the questions that needed conceptual understanding of the unit of forces and motion, the post-test result showed that for the 32 questions, 80% of the students answered 30 questions correctly. Only two fell under 80% but were still above 70%. Therefore, the first theme identified in this research study was narratives and real-life examples. The collected data showed students’ inspiration and strong concept development and understanding of science through narratives and real-life examples.

Engaging and Empowering Learning Through NGSS

Although students were not yet thoroughly familiar with the NGSS teaching method and, in rare cases, wanted traditional education, including lectures and note-taking similar to what Bonner (1999) mentioned, most of the students found this method very beneficial for learning and becoming prepared for high school. The following data shows how NGSS positively impacted students learning. Most students found learning through NGSS fun, mainly because of the real-life hands-on and technology-based group work that needed creative design. For example, Hunter believed, “[b]uilding and designing the car project was
a lot of fun and helped me learn a lot. I could work with other people and learn a lot in the process, which is the best kind of learning for me.” Likewise, Dana also mentioned that:

The most fun experiences in this class were the hands-on activities. The car project is a really good example of this, doing research, working with others, creating and designing, etc. were really helpful and definitely strengthened my understanding of the topic."

Therefore, the second theme identified in this study was learning science through the NGSS. In what follows, I describe the 3D car project as the main group hands-on activity for the forces and motion unit. Then, I will analyze the importance of group work and, finally, the impact of each component of NGSS on students’ problem-solving, concept development, and concept application skills.

**Description of the 3D Car Project**

Students collaborated remotely in Google breakout rooms with their group members to create their 3D cars on Tinkercad websites. Students then forwarded their final design to the teacher for printing, considering all the scientific criteria required for their cars to travel fast and far. Printed 3D cars were shipped to the online students and handed in class to those who attended in-person during school opening. Finally, students assembled, colored, and tested their cars. Each group also created an electronic journal following the engineering design process, presented it in class, and shared the video of their car testing to demonstrate their proficiencies and knowledge obtained during this unit.

Since it was my first time using a 3D printer, I was unaware that it might not be able to produce small objects precisely. As a result, teams that designed their wheels to be very small and thin to reduce friction and increase speed did not print well, and in most cases, the
wheels broke by removing the residues with sandpaper or scissors. Due to the limited time, the teacher purchased premade wheels for the students if they found the printed wheels were not working well for their project. Even though developing the wheels was an essential part of the process, they still needed to design and build a 3D car considering other criteria and constraints such as its mass, speed, power, and an appropriate ramp that allowed their cars to travel at least 5 meters.

The 3D car project was designed to help students learn about the engineering process while applying knowledge from forces and interactions, emphasizing balanced (Newton’s first law) and unbalanced forces that affect motion. They also needed to explain why their 3D car kept moving and stopped moving after traveling a certain distance. Students applied Newton’s second and third law of motion to related forces to justify the motion of the 3D cars. Therefore, students were required to plan and investigate collaboratively to provide evidence that the sum of the forces operating on the car determines its motion; if the total force acting on the 3D car is not zero, its motion will alter. Furthermore, the larger the car’s mass, the more force is required to achieve the same change in motion, and more force creates more motion changes.

Finally, students needed to connect evidence and explanations logically and conceptually to show that they examined their design constraints, made revisions, and decided on a final design while keeping the budget and time in mind. The teacher was also responsible for purchasing the materials needed for this activity and printing the 3D cars. Students were required to keep their designs at the maximum width and length of 5cm by 12cm to print all the cars during the Spring break.

*Group Work*
The data from surveys, interviews, and videos showed that grouping the students based on varying knowledge and skills allowed them to share their interests, talent, and capabilities while working together to improve their work, skills, and learning. In such a way, students tended to do high-quality work and present it to others for recognition. Although some student survey data showed that a few students had preferred only in-person interactions for learning, other students indicated that online class discussions, labs, and breakout rooms were beneficial to their learning. However, working in an encouraging and fun environment where all work together simultaneously was the critical factor presented in the data.

The functional role of peer-to-peer interaction is supported by student responses to two survey questions asking about the class’s least and most engaging activities. For example, Carlos saw the interactions via breakout rooms as helpful for engagement and learning as he mentioned that: “[t]he most engaging activities are when we are in breakout room we actually get to communicate.” Students also found class discussions effective for their learning because of the same reason. Moreover, they liked peer-to-peer interaction during the car project because they could get help from each other and learn. For example, Leslie indicated that class is engaging when the teacher “puts us in groups because the class has to help each other.” This is also more evident in Nima’s email to the teacher, indicating that he was inspired and learned significantly through the class discussion, as shown in Figure 7.

On the other hand, most students believed that the least engaging activities were individual online work for a lack of peer support. For example, Juliet explained why she does
not like individual work: "You can talk it over to someone if you do not understand the question.” Peer teaching seems to be the important factor for Juliet liking group work.

Figure 7: Student Email About Class Discussion

Figure 7 is related to Newton’s three laws of motion class discussion. Students needed to develop examples related to each law and explain them thoroughly. After reviewing the laws of motion, the teacher talked about the importance of learning science and the role of science in life. The teacher also showed students videos related to the Sentinelese and Toulambi tribes, who still live like the stone age people in this era. Most of these tribal people even refuse to interact with the modern world. Therefore, throughout the class discussion, students discussed the pros and cons of science and technology in life and concluded that science improved the quality of our lives, from advanced technologies for communications and transportation to medications and treatments. In the end, the students also discussed the positive impact of knowing Newton’s three laws of motion in life.

Throughout this research study, students worked in groups for all the projects and activities related to the unit of forces and motion. Therefore, it will be discussed how the group formation characteristics influenced students’ collaborative work toward a common learning goal. In this study, students collaborated with their peers with almost no complaints from their partners. Students indicated that this is because they worked with their friends. To
group students, students provided the names of 3-4 classmates they preferred to work with on the 3D-car project in the pre-test. I also checked their academic and skill abilities to group them and make sure not all high-performing or low-performing students were in one group to help students better learn from each other (Assinder, 1991). Each group also chose a leader to manage and monitor group work to achieve their goal. Students took responsibility based on their strengths. The following quotes are student experiences working in a group for the 3D car project. Even though most students indicated successful online group work, many still complained about communication. For example, in response to the interview question asking about their experiences working in a team, Maryam explained the positive effect of this group formation strategy and compared this group work with individual work and her past group work experiences.

Maryam

My experience working in a team was very good. I mostly had group members that were really dedicated to our project and were actively social. Having a group really helped out because it made the project really fun and split up the work. I think I could do the project on my own if I had to, but it would take forever and wouldn’t be fun at all. I think that the most important part of making group work fun is to make sure everybody is in a group that they are comfortable talking to and working with. I hate being in groups with people who don’t care enough to work or with people who are too shy to speak up because then I end up in a position where I am doing all the work on my own, and then the other group members who didn’t contribute still get the same grade. That being said, if I am in a group with people who are social, and do want to work, then it can be a very fun experience.
It is evident in Maryam’s response that when everybody does a job based on their interest and capabilities in a group, they feel confident to speak and share their knowledge in a friendly environment rather than not participating because they do not know what to do. For example, she found that her group members were dedicated to the project. She also mentioned that group members were comfortable talking and working cooperatively. Hanna also agreed on the effectiveness of the grouping and group work but also mentioned that the group work motivated her to do work on time. This motivation seems to be part of the science identity because Hanna’s responsibilities reflected her capabilities and confidence.

Hanna

During online school, it was very challenging to stay motivated and talk to my group mates. But it wasn’t very hard to work on everything together. My role on the team was doing research and helping with the slides. We all agreed on everything with the exception of a few things. If I had done it by myself, I probably would have lost motivation and waited until the last minute to start the project. The teacher couldn’t have done anything to improve our teamwork. She did a good job guiding us and was very helpful.

Hanna’s quote also emphasized the teacher’s role as a facilitator and mentor in their learning and group project. Likewise, Isaac reiterated motivation and time management as the benefit of group work. He also experienced teacher support. Although he did not mention the term science identity, he talked about its features, such as group work. Like other students, he also found online communication difficult during the 3D car project.

Isaac
The challenges of having an online group was obviously having technical difficulties, us not talking to each other and only using the chat, and of the lack of communication. The benefits of it were that we could make a car in online software, and was not a struggle physically. It was important to be working as a team, or else I would have a lack of motivation and procrastinate on the car project. I would have done a poor job if I wasn’t in a group.

Both Hanna and Isaac also mentioned that working in groups during online school had a motivational effect on them. Finally, Niko believed that group work was a helpful factor that led to a positive classroom environment for learning. In addition, by looking at other students’ work, Niko was able to compare his work with others during the group work to make sure he was on the right path. For example, Niko said, “we all have fun trying it out and seeing other people try it. It’s fun and interacting.” I analyzed these statements as learning with building confidence because all the above factors provided a supportive environment that integrated students’ interests, engagement, sense of belonging, and finally, science identity. Individuals build science identity when they experience success and receive support from important people (Aschbacher and Roth, 2010).

**Students’ Work Based on the NGSS Dimensions**

According to Next Generation Science Standards Lead States (2013), the new standards are based on three dimensions.

- The science and engineering practices (SEPs) that describe behaviors, scientists and engineers participate in.
- The core ideas which describe the main ideas in the science disciplines Disciplinary Core Ideas, (DCIs).
Crosscutting concepts (CCs) that describe the science concepts linking the different areas of science.

The standards have been developed based on student performance expectations, which explain what students should know and do by the end of the lesson. Each performance expectation establishes the three dimensions and consists of a science and engineering practice, a disciplinary core idea, and a crosscutting concept, and the expectations are not the instructional objectives (Next Generation Science Standards Lead States, 2013). Therefore, I determined which ideas were essential for the students to learn based on the essential ideas mentioned in the NGSS framework, students’ background knowledge of the topics, and mainly based on their interest in activities that could engage them so that they could learn online (Krajcik et al., 2008). For example, students learned speed calculations and ways to minimize air friction by making a paper airplane using the NASA website (NASA, 2021). I selected this activity based on students’ preferences for more hands-on activities indicated in their feedback on previous assignments. I also offered more technology-based activities using Webquest and Tinkercad to improve students’ interests and learning.

**Fostering Ongoing Skill Development Through Science and Engineering Practices**

According to Next Generation Science Standards Lead States (2013), “the Scientific and Engineering Practices are not teaching strategies, they are indicators of achievement as well as important learning goals in their own right” (p. 2). Thus, the students’ learning was evaluated based on the following learning expectations for this section; (MS-PS2-1), (MS-PS2-2), (MS-PS2-5), (MS-ETS1-1), (MS-ETS1-2), (MS-ETS1-3), and (MS-ETS1-4). Detailed information on these expectations is outlined in Appendix D.
Engineering Design and Practices delves into the methods engineers use to identify and address issues, and their categories follow the engineering design process (Next Generation Science Standards Lead States, 2013). Therefore, Next Generation Science Standards Lead States (2013) highly recommended emphasizing the core ideas of engineering design and technological applications in science instruction to the same level of scientific inquiry. According to Turner et al. (2016), engineering design is one of the NGSS standards, but teachers can teach core content and science and engineering practices through engineering design. The stages of the engineering design process are as follows:

**Asking Questions and Defining Problems.** As it is evident in Kevin, Hendrick, Ali, and Addison’s group’s electronic journal (Figure 8-13), the team recorded their research questions and constraints that needed to be answered. For example, how to get the most distance possible. They also recorded the best solutions found through research, such as using a sail-car and using a fan for infinite distance (Figure 8-9) (MS-ETS1-1).

**Planning and Carrying Out Investigations.** The group also collaboratively designed the 3D car, as evident in their time log (Figure 9). They used their thoughts, background knowledge, interests, problem-solving and creative skills, considering scientific ideas and principles learned during the forces and motion unit and through research to sketch their design (Figure 10). For example, they thought of different materials that could be used for the ramp for the best outcome and stated their rationale for selecting materials (MS-PS2-2). They also clearly showed all the essential parts and variables of the car, but they forgot to include the measurements used on the blueprint. One reason for this omission can be because they followed the rubric and kept the size of the car under 5cm by 12cm, and they did not think they should record the exact measurements. The other possible reason is that they relied
on their computer design on Tinkercad as the most reliable format, which had the sizes and dimensions (Figure 11).

**Developing and Using Models.** Finally, the group built their sail car and tested their theory. They collected data to calculate the speed using the correct formula and units (MS-ETS1-4) and evaluated their design (Figure 12-13). As a result, the evidence also met their expectations (MS-PS2-5).

**Constructing Explanations and Designing Solutions.** Kevin explained that they had first designed a circular ramp covered with aluminum foil during the group presentation, but the car was not moving fast. Finally, they modified their circular track to a meter-long cardboard trail (Figure 9) and powered their car by turning on the fan next to each end for an infinite distance and overcoming friction with the high wind (MS-PS2-1).

**Analyzing and Interpreting Data.** Kevin’s group recorded their data and calculations. They analyzed their data and explained that they needed to keep the fan at a constant angle around the ramp to keep the car moving circularly. Otherwise, the car kept hitting the edges of the ramp. However, they only needed to move the cardboard track in front of the fan in their improved design (Figure 13) (MS-ETS1-3).

**Engaging in Argument from Evidence.** Kevin’s group solution for distance passed the requirement needed for this project. However, the speed of their car was not as fast as other groups. Yet, the group extensively addressed the criteria and constraints such as materials, the visual representation, the power, and the car’s overall performance by choosing a meter-long track (MS-ETS1-2).
Sail Cars

Kevin, Hendrick, Ali, Addison

Engineering Design Process

1. Ask: We asked scientific questions about our car, for example: what engine would work best.
2. Research: We researched about the questions we asked and we came up with enough information to start thinking of ideas for our car and decided to use a sail.
3. Imagine: We thought of many ideas and eventually came to a conclusion using our research.
4. Plan: We planned our design and made it in Tinkercad.
5. Test: We tested the car to see how it worked.
6. Improve: That design didn’t work too well so we revised it and came up with a better and more interesting design.
7. Test again: We tested the car to see how it worked.

Questions:
- How should we format our car with the sail and what is a good sail material?
- What is a good material and design for building a track?
- How can we overcome wind resistance?
- How do we get the most distance from using a sail?

Figure 8: Group’s 3D Car Electronic Journal Part 1
Figure 9: Group’s 3D Car Electronic Journal, Part 2
Figure 10: Group’s 3D Car Electronic Journal, Part 3
Figure 11: Group's 3D Car Electronic Journal, Part 4
Figure 13: Group 3D Car Electronic Journal, Part 6

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<td>297 m / 889 s = 0.334083 m/s</td>
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<td>Total Seconds Traveled: 889 seconds</td>
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<td>Overall Speed: 0.334083 m/s</td>
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**FINAL RECORDING**

The video went on for about 15 minutes like this, but because the file was too big we unfortunately had to cut the video really short.
The leading prominent sub-theme identified during the coding process for NGSS was the importance of the engineering design that raised students’ interest and engagement to apply their scientific concepts in designing the 3D car project. The students needed to use their creativity, critical thinking, and problem-solving skills during this process to invent the new 3D car that travels fast and far. From a global perspective, two main components of engineering for the K-12 level are “innovation” and “creativity” (Next Generation Science Standards Lead States, 2013, p.2). In the engineering field, engineers should be able to solve the world's challenges and generate new inventions. Therefore, inspiring K-12 students with engaging activities and a rich foundation in engineering design to enhance their interest in STEM fields and careers and prepare them to solve the critical societal challenges and environmental concerns in the future is critical (Next Generation Science Standards Lead States, 2013). In this study, students’ electronic journals, the 3D cars, surveys, and interview data represent the students' level of interest, creativity, and innovation in this phase. For example, Nedda found this type of project challenging, fun, motivational, and educational as she explained,

The 3D project has made science a funner and more enjoyable subject for me.
The project certainly challenged me, having to work with other people, doing it virtually, etc. The challenge has definitely improved my understanding of science, having to do research and use online resources to improve my learning. The difficulty and challenges in this project were balanced out by the creative and designing factors which made the project not only informative, but also fun. I would say I like science a lot more now and the project motivated me to work hard and take my science learning a lot more serious.
More examples of students’ work also show the positive impact of creative design on students’ scientific literacy. For example, to build the car project, students needed to apply all the scientific concepts to design the ultimate 3D car. According to Utami et al. (2019), critical thinking, problem-solving, decision-making, creativity, and innovation through communication and collaboration are the components of 21st-century learning. Moreover, information and communication technology (ICT) and literacy are the tools to achieve this goal. A person’s scientific literacy refers to their ability to seek, locate, or determine answers to questions arising from ordinary encounters (National Research Council, 1996). In addition, it denotes a person’s ability to explain, predict, and characterize natural processes. Scientific literacy is determined in various ways, such as correctly employing technical jargon or applying scientific concepts and processes (National Research Council, 1996).

Another example from Brooklyn’s group electronic journal shows the application of scientific literacy during creative design. For example, first, they defined the word friction in their 3D car journal and its effect on their car project. Then, they explained possible ways to minimize friction for the best result. Finally, they improved the design using their problem-solving skills to meet the expectations. The following information shows how students tried to apply the scientific concepts in designing the 3D car. The following is the information from Brooklyn’s group electronic journal.

**Friction:** The resistance that is caused by two objects rubbing against each other.

Friction causes objects to slow down, so we want our car to be exposed to the least amount of friction as possible. Here are a few things we are doing to reduced friction:
- Racing our car on a surface with low friction
  - Possible surfaces: Wax paper, printer paper, fabric, or pavement
- Making sure our car is light
- Making sure the car has limited surface area touching the ground

We also need to consider how the different types of friction will affect our car.

Finally, the group indicated solutions they used to improve their model. For example, they mentioned, “We tested with the premade wheels, but they were sliding around, so we put tape on the axles to keep it from sliding,” and “[w]e experienced setbacks with our wheels so we extended the ramp so that it could gain more distance.”

**Student's Engagement and Acquisition of Learning During Disciplinary Core Ideas (DCIs)**

The next stage of the NGSS is the DCIs which are the scientific requirements to comprehend a particular science discipline (Next Generation Science Standards Lead States, 2013). According to Krajcik (2016), DCIs are conceptual tools students can employ to make sense of phenomena or solve issues. Therefore, using these tools for teaching also leads to a deep understanding and application of content. In addition, the conceptual tools teach learners more about the world as they use them to investigate and explain occurrences and solve issues throughout their lives. Hence, instead of teaching them more details of content, the teacher assisted students in understanding the “how” and “why” across different phenomena (Pellegrino and Hilton 2012 as cited in Duncan & Cavery, 2015, p. 52).
8th Grade NGSS Core Ideas for Instruction and Assessments. The following core ideas were used for instruction and assessments during the forces and motion unit to allow students to use them to discover the content information and practice problem solving using scientific or technological knowledge to make sense of phenomena. Detailed information regarding the core ideas can be found in Appendix B.

- PS2.A: Forces and Motion: (MS-PS2-1) and (MS-PS2-2).
- PS2.B: Types of Interactions: (MS-PS2-5).
- ETS1.A: Defining and Delimiting Engineering Problems: (MS-ETS1-1)
- ETS1.B: Developing Possible Solutions: (MS-ETS1-4), (MS-ETS1-2), (MS-ETS1-3), and (MS-ETS1-4).
- ETS1.C: Optimizing the Design Solution: (MS-ETS1-3), and (MS-ETS1-4).

The National Science Teachers Association (2014) lists four requirements for a DCI. A DCI must meet at least two of these, but ideally, all four, including:

- Have broad importance across multiple sciences or engineering disciplines or be a key organizing concept of a single discipline.
- Provide a key tool for understanding or investigating more complex ideas and solving problems.
- Relate to the interests and life experiences of students or be connected to societal or personal concerns that require scientific or technological knowledge.
- Be teachable and learnable over multiple grades at increasing levels of depth and sophistication.
As evident in students’ electronic journals, using narratives, real-life examples, bellringer activities, and hands-on group activities helped students formulate theories, investigate utilizing scaffolded experiments, and draw conclusions connected to applied forces and the resulting change in motion. Students also solved problems and made their best decisions for different components of the 3D car project for the utmost outcome during this process. For example, Kevin’s group designed a wind power model for ongoing movement. To achieve this goal, they planned for a farther distance, and they did not limit their project to the limited length of 5 meters. Secondly, the group assembled their 3D car as they were engaged in evidence-based arguments. Lastly, students documented their questions and ways to solve them, considering the scientific facts and laws and prioritizing specific criteria over others (Figure 14-15). Students' post-test results also support this coherent learning.

The results of 43 out of 51 pre-and post-tests were used for analysis. I followed the assessment strategy used by Zhang & Probst (2016) to compare students’ learning before and after this unit. For more accuracy in the result, Zhang & Probst (2016) used a subset of problems that could easily be understood by all students from the pre-test in case some students answered some of the multiple-choice questions randomly from the full set. In this research, students needed to define the vocabulary for most of the questions. Since students were unfamiliar with most of the pre-test questions, I also decided to choose 16 questions from the first part of the pre-test, which could easily be understood and defined by all the students for the assessment analysis. The question numbers are (1, 3, 4, 5, 7, 10, 11, 15, 17, 19, 22, 23, 27, 28, 30, and 31).

Table 1: Pre-Test Result (43 students)

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<th>Question #</th>
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The data in Table I and Figure 14 show that questions (1, 3, 4, 28, 30, and 31) were easy as 70% of the students answered them correctly before learning during this unit. These questions are basic questions related to motion, speed, and distance versus time graph. On the other hand, only 50% of the students showed understanding of questions (10, 11, and 19). Students needed to define mass, weight, and stationary for these questions. Finally, less than 50% of the students knew questions (5, 7, 15, 17, 22, 23, and 27). These questions mostly needed a conceptual understanding of balanced and unbalanced forces, friction, momentum, and acceleration. These questions are the main fundamentals of the unit of forces and motion, necessary for understanding Newton’s three laws of motion.

**Table II Post-Test Result of Complete Set (43 students)**

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*Figure 14: Percentage of the students with the correct answer in pre-test*
Students took the post-test at the end of the unit, which contained the same complete set of questions as the pre-test. To ensure that students answered the questions based on their knowledge and did not use the online resources, I monitored their work on GoGuardian (Alim et al., 2017). Many students also took the post-test in class during in-person school. The result is shown in Table II and Figure 15. Among 32 questions, 80% of the students answered 30 questions correctly, and only two questions fell under 80% but were still above 70%. For these two questions, students needed to define momentum and acceleration. Although most of the students understood the concepts by explaining these words correctly, I did not use those answers for this research as I expected to see the same definitions and keywords we used and learned in class during this unit. For example, students defined acceleration as the measurement of the change in an object’s velocity. At the same time, I expected to see the word “time” in their definitions, such as the change in velocity divided by time interval. We also discussed momentum as mass times velocity. The more mass an object
has, and the faster it’s moving, the greater its momentum. However, students defined momentum only as the quantity of motion or used similar definitions. Only less than 30% of the students used other definitions than what they had been taught in class.

The comparison data between pre-and-post-tests also shows significant improvement in learning the content based on narratives through NGSS constructivists pedagogy (Figure 16). Students not only learned the definitions of the scientific words, but they also learned how to solve problems that needed calculations performed with correct units.

![Comparison between Pre-Test and Post-Test](image)

*Figure 16: Comparison of the correct rate in pre-and-post-test.*

In 1998 Hake introduced normalized gain as a measure of the effectiveness of a course in improving conceptual understanding. Hake proposed the following formula for measuring teaching effectiveness based on knowledge gain (Hake, 1998).

\[
\text{Normalized } g = \frac{\text{class posttest avg }\% - \text{class pretest avg}}{100\% - \text{class pretest avg }\%}
\]
According to Hake (1998), a g-value higher than 0.7 is high, between 0.3 to 0.7 is medium, and lower than 0.3 is considered low. The normalized gain for this study was \( g = 0.78 \). This value indicates that the NGSS-constructivist teaching pedagogy used in this study highly impacted students’ learning physics concepts of forces and motion.

**Power of Students’ Imagination and Innovation During Crosscutting Concepts**

The NGSS Crosscutting Concepts connect the many DCI to give a seamless learning experience for students (Appendix E). Such notions can connect each of the four DCI areas, including Physical Science, Life Science, Earth and Space Science, and Engineering and Technology paving the way for more profound levels of comprehension and application (KNILT, 2019). Furthermore, students should establish predictions for any modifications they will make to the model during this phase and then observe their adjustments' effects (Next Generation Science Standards Lead States, 2013).

Therefore, during the Crosscutting Concepts, students in each group made predictions based on changes they had made to improve their 3D cars and observed the effect of the changes. They also recorded failures and ways to enhance their 3D cars in electronic journals. For example, Savannah’s group put rubber bands on the wheels and added a balloon to accelerate the car’s motion, as shown in Figure 17. After testing the original car model powered by gravity, they described that “[w]e tried out our car and found that the wheels weren’t the best. They had too much room to slide around on the axle and were a bit too big for our liking.” However, after the improvement, they explained that “[w]e went back and fixed the wheels and then put rubber bands on the wheels to reduce friction and a balloon on the top to help power the car.” As a result, with less friction and more force through the
balloon and gravity, the car's speed increased by 0.83 m/s. The final speed of the car was 1.18 m/s.

During the class presentation, the teacher asked about the cause and effect as the dependent and independent variables to guide students to see if they understood that there might be a chain of interactions instead of one reason leading to an effect (Next Generation Science Standards Lead, 2013). For example, Savannah’s group explained different types of friction such as air and rolling friction, the force of gravity, the force of the balloon, the mass of the car, and the size of the wheels as the independent variables or the cause, and the car's motion as the dependent variable or the effect. The group communicated the cause-and-effect relationships of the phenomena and provided evidence to support their reasoning. They were also able to get more profound than the causal relationship. They explained how the control of the independent variables led to the dependent variable they wanted based on their design. Finally, they used charts to analyze patterns in data and calculate the car's speed. This indicates how students internalized and transformed new science information by forming new cognitive structures to create new understanding (Kim, 2005).
In general, students created, tested, assessed, built their 3D cars, documented iterations, recorded data, and did speed calculations using the correct units. They also presented their overall group work, supporting their choice using the information gathered and math calculations. Finally, group members presented their electronic journals in class to demonstrate proficiency in constructing explanations, designing solutions for different parts of this project, and understanding the core ideas. Yet, students showed collaborative incentive design through technology as the most exciting and helpful part of the NGSS.

According to the Next Generation Science Standards Lead States (2013), the NGSS offers a more rigorous approach to teaching science through inquiry learning. The NGSS employs discovery learning to teach students scientific material and skills in the context of real-world occurrences. This is also evident in our data as the students learned the scientific content deeply through inquiry-based learning rather than memorizing facts. Students also explained that this strategy assisted them in applying their scientific knowledge to build the 3D car project and enhanced their science identity as they felt confident demonstrating their understanding of the scientific facts, theory, and laws by making the 3D car project.

Finally, student responses to the post-interview question determined that they were confident about their scientific knowledge after being taught science through NGSS-based pedagogies. Students explained various reasons, such as understanding the content instead of memorizing, using real-life examples, learning by doing and thinking instead of notetaking, and using their creativity and problem-solving skills rather than following the scientific method steps. They also restated the role of a positive classroom environment in their learning. For example, in response to the post-interview question asking how confident they are about their scientific content knowledge being taught through NGSS, Angela said:
I am very confident enough about my scientific knowledge this year because we did better experiments than in my other science classes. In my other science classes, the projects were all about the organization of notes, constant observing steps, and more writing. Also, this teacher’s environment just seems more calm since she isn’t yelling for anyone to hurry up to do something, and if that happened instead, I would be too freaked out to get anything done.

Mitra

I think I learned the content really well because of this new curriculum. Instead of taking notes for the whole class we did a variety of things to help our learning. In some subjects, like math, notes work for me but I feel like in science it doesn't work too well. I also feel like I have learned a lot more science this year than any other year before, so I believe the new curriculum works pretty well.

Cody

I learned a lot more, and I actually understand it. I am very confident because I had a teacher that used examples, went over answers, and generally taught a great class. I learned so much and I will be prepared for when I go into high school science.

Sam

I am pretty confident because the teacher taught us in a way that's going to stick in my mind for a long time. She kinda hammered it into my brain (in a good way) so I don't feel like I'm going to forget it anytime soon.

**Teacher’s Role in Promoting Respect, Dignity, and Integrity for Higher Achievement**

To prepare students for their future professional life and jobs, I treated them with more respect for who they will be in the future. I called them with prefixes such as Mr., Ms.,
Dr., Professor, and even President to allow them to visualize themselves in the future and prepare themselves for those jobs by acting more maturely. The survey and post-interview data show students enjoyed and cherished by teacher’s respect and learning about manners. For example, Lili said,

She really taught me about life skills that weren’t science-related. She managed to teach us and give us important moral lessons that could be very helpful in the future. She shares her past experiences with us sometimes, which makes us learn about what is right and wrong in this modern-day world. Her stories were deep and meaningful life lessons that I will take with me in the future.

To students, respect along with equity was also more noticeable and valued. They wanted to be treated the same in other classes besides science, especially the low-performing students. One strategy used was approaching low-performing students and politely asking them the best method to help them perform better in science and prepare for high school or, in general, their life. These students revealed that the teacher’s help meant a lot to them, mainly because she did not put them down for their lack of work or skill development, especially in front of their peers. For instance, Jayden’s response shows how valued he felt by receiving respect from the teacher as he said;

I think that this teacher is really nice and respects everyone for who they are. She always looks for the best in everyone and sometime I wish my other teachers would do that too. She also says thank you, and you don't treat anyone differently because of their grades of how they look. I also like how you say "Miss and Mr" it's very formal and shows that you don't think lowly of us or anything.
Some students mentioned that they had been yelled at in other classes. Yelling is different than being firm. In some cases, such as classroom management, teachers might be more firm yet kind to the students (Balli, 2011). Students and I created mutual respect to strengthen our relationship in my classes. Students were not only treated with respect during my classes, but they also learned about respect and integrity and their importance in our lives. For example, I shared a few real-life stories, such as a test grading strategy involving all the students without realizing that it had been planned to teach them honesty and respect for themselves. After any test during the forces and motion unit, I reviewed the answers in a class by asking students to share the answers and grade their own tests. They also needed to write the number of the questions they got wrong next to their grades. That strategy was planned to let students review the science materials one more time and put them in a situation to decide to be honest or not. Although they knew that I always grade their work by myself, and this was just a practice for them to learn honesty, some students have thought I would not grade the tests again, using the logic of why would I have asked them to grade their own tests? Although they did not lose extra points for their dishonesty, I noted them and listed their wrong answers while grading their tests. In deceitful cases, students graded themselves about one to ten points higher than they should be. With this grading strategy, I wanted students to feel the fear of dishonesty; I wanted those students who grade themselves higher to feel shame when they see my notes indicating their actual grade with a list of wrong answers, and it was my hope that they never make such a decision in the future.

The goal was more than a grade for a science test, and I wanted them to learn and not make such mistakes again in any aspect of their life in the future. There is only one chance in most real-life situations, and the impact of dishonesty might be significant. More
importantly, my goal was to teach my students that creating trust by respecting themselves and working with honesty brings them peace, and people reciprocate their actions with admiration. Otherwise, because of a lack of trust and honesty, they might face more rules, limitations, and boundaries in any place they work. When I shared my intention of using this grading strategy afterward, students started telling me about their stories, feelings, and possible decisions that came to their minds while grading their tests. Some explained why they decided to be honest. Shirley also sent me an email, shared her thoughts, and thanked me for teaching her more about respect and how our class discussion changed her perspective (Figure 18).

Students also suggested continuing teaching respect to future students. For example, Scott said: “I really like the story that she told our class how anyone can really make mistakes but in the end its going to end up being okay. but also, to be careful of your decisions.” Tony mentioned that “all teachers should tell us stories that teach us life lessons about things like respect and kindness. I think these are very important things to learn about, and stories are one of the best ways to learn about these things.”

*Caring and Understanding are the Keys to Success*

Teaching is all about caring; otherwise, no one learns as much as should be learned. Students need to be recognized and admired for their unique abilities and interests (Lumpkin, 2007). Many teachers, instructors, and professors taught me a subject during my education.
years, but I only remember those who taught with more care and helped me find the best way to succeed. In my teaching pedagogies, I wanted to be one of those caring teachers who significantly affect students’ lives, not the ones that will be forgotten easily. Therefore, instead of positively or negatively judging students, I decided to ask students about their plans, goals, and constant feedback on each assignment to find their best learning and teaching strategy. Since my teaching goal was student learning, I prioritized students’ learning and helped them in this manner. I provided extra help during my office hours, gave them extra time to do their work, divided their missing work into smaller portions, followed up, and even gave them another opportunity to show their learning after the tests. These additional opportunities were not because I wanted to be nice but to help the students learn the necessary science materials and prepare for high school. Student responses to the survey and post-interview questions also support the effectiveness of teacher’s care. For example, Sarina mentioned, “[s]he pushes you to try your best. One time I didn’t turn in work for a while, and she helped me get back on track.” Mary and Aiden also had a common point indicating that the teacher made the lesson more personal to the students and their future.

Mary

The teacher is especially good at connecting with her students and always giving her best to the job. She tells stories about her own life, relating to what we're learning in class, which makes the lessons more personal. You really feel like she cares about your learning and that makes it easier to want to engage and pay attention. You can tell she loves her job, and she never seems to bring her problems into the classroom.
She always has a smile on her face and she really tries to engage everyone in the class.

Aiden

The teacher should keep asking questions to students and test them. She should keep being curious about someone's future too. I like when the teacher often asks questions and does ask about us, it shows that she cares. It makes me want to work harder since she shows she cares so much... Bottom line, she shows that she cares and it makes me want to be better.

Students’ survey responses also show individuals’ positive experiences with the teacher’s understanding and its beneficial reinforcement effect. For instance, James saw the teacher’s care and understanding in offering various activities to address the needs of all the students as he stated:

She should continue to give us assignments that involve different ways of learning and understanding. It's more enjoyable to have different types of assignments instead of just work pages. We do interactive work and all these assignments that are different.

Charlotte defined the teacher’s understanding as receiving help for late assignments and extra explanations for better learning the topic. For example, she said, “If I have a late assignment, she is kind and understanding about it, and she is very helpful if I ever have any questions or get confused.” Finally, Luca experienced the teacher’s understanding when he was tired as he mentioned, “[s]he shows sympathy if we are tired. She wants us to have fun and be interested.”

_Growth Mindset by Creating a Safe Classroom Environment for Diverse Cultures_
Every person desires freedom, power, fun, and being loved. Providing such an environment is also a strong foundation for high-quality learning (Erwin, 2004). Therefore, creating a culture of trust, respect, care, and high expectations, and also asking students for feedback on class activities, and offering a variety of activities worked together in my classroom environment to increase engagement and facilitate the active participation of students.

In my teaching pedagogy, part of the teacher’s care was letting students share their thoughts, beliefs, and concerns if they were interested in a safe environment to educate others about diversity and learn how to treat others with respect and dignity. The goal was to help students learn about diverse cultures to feel more comfortable and safe, dealing with these differences now and later in life.

While a growth mindset typically refers to personal conviction, some researchers suggest it can also act as an emerging cultural element of the environment (Murphy & Dweck, 2010; Canning et al., 2019). Therefore, I tried to create a supportive classroom environment where students could talk about their culture, beliefs, and values throughout the school year by sharing many life lessons and even sharing stories from my life as an immigrant. The data supported this goal as students showed interest in sharing their unique culture, beliefs, and values in such a classroom environment. I have also tried to add and expand on what students shared in class to support them in the way they were. Sometimes, I shared similar experiences, and students mentioned this strategy made them interested in talking about themselves in class because they received my support. Selma called these types of lessons “moral lessons” that she needed to know for her future as she stated, “the teacher really taught me about life skills that weren’t science related. She managed to teach us and
give us important moral lessons that could be very helpful in the future. She shares her past experiences with us sometimes, which makes us learn about what is right and wrong in this modern-day world. Her stories were deep and meaningful life lessons that I will take with me in my future.” According to the survey result, Carlos also mentioned that “I would have this teacher continue to help us toward a bright future and give us examples of it,”

Most of the students mentioned that they felt accepted and valued in the class community because of this strategy, especially minorities (Vygotsky, 1978). For example, Marco, an ESL student, was always too shy to talk in our online class, but he started talking and asking questions during in-person school. He told me that he found the class environment like his “home” and felt comfortable talking regardless of the little English he knew.

On the other hand, some other students sometimes used inappropriate language while talking to their peers. I realized that part of it is because they do not have a good foundation for speaking politely, especially in public places like school. For example, Andrew blamed his parent for his unprofessional behavior and being irresponsible with his academic work. He said that his mother always uses informal and inappropriate language at home. I told students that the way they act and speak to others indicates how people treat them. Therefore, I shared more life lessons about manners and kindness. I also taught them how to write a professional email to show their respect and kindness to people who typically work hard for them and deserve to receive a thank you message, such as their parents/guardians and teachers. Figure 19 shows Vida’s appreciation emails to her parents. As evident in the student’s emails, they used polite and professional language to show their kindness to their parents and teachers. Finally, Figure 20 is an email from a teacher who received students’
appreciation emails. The teacher’s email offers how happy and thankful she felt for the students’ emails.

Figure 19: Student’s Kind and Respectful Email to the Parents

Figure 20: A Thank You Email from A Teacher Who Received Kind and Respectful Emails from the Students

Students’ responses to the post-interview questions also illustrate ways that that classroom environment impacted them. Students explained that they felt safe, supported, recognized, treated with equity, and encouraged to do their best for higher achievements by addressing their needs. For example, in response to the interview question asking, could the teacher create a positive classroom environment? Samim said, “I think our classroom is
already a very positive place, especially because I feel like a lot of my peers feel safe coming to her about things, and I always feel welcome in her class,” and Alex said,

Yes, I think the teacher is great at what she does. she’s one of those teachers that I don’t get bored with in class compared to other teachers. For example, she does life stories, group work, videos and everything she could of possibly done. she cares about all of her students very much and I can’t wait till I can communicate with her in the future when I have a good. If I did really good in life this would for sure be one of the teachers I would remember. The teacher deserved to be a millionaire!!!

As evident in the above responses, students defined a positive classroom environment as a place where they feel supported and encouraged to learn through various strategies. Some other students also revealed that the teacher’s greetings at the door or even greeting them online as they entered the Google Meet created a positive classroom environment along with other factors mentioned above. They also mentioned that they felt welcome and received positive energy from the teacher’s positive behavior, which is evident in Valeria, Joshua, and Amy’s responses to the survey question about the classroom environment.

Valeria

The teacher had a superb talent in creating an excellent environment in the classroom, online and in person. She would always greet us and help us when we needed it. She did not show frustration with anybody, but instead showed patience and kindness.

Joshua

I think the teacher has created a positive classroom environment just by coming to class every day excited to teach us and including everyone. All of the materials in the classroom online and in person are easy to access and all of her instructions are clear.
Amy

I think the teacher could create a positive classroom environment by being friendly and just talking. I think that she already has done a great job of it this year because even before stepping into her classroom (or logging into her classroom) I already know that she is going to be friendly and lift up my spirits. I think that just a little bit of kindness will go a long way in this classroom, and that’s what makes her classroom so enjoyable.

Moreover, both Valeria and Amy indicated the effectiveness of the teacher’s consistent behavior on students’ positive attitude to learning. Finally, Joshua showed the organization of the materials and clarity of the instructions were also part of the effectiveness of the classroom environment.

Throughout the data, almost all the students mentioned that they always had experienced support from the teacher. Students’ responses to the survey question asked, what are the things that this teacher does that you want all your teachers to do? The general answer was that the teacher’s support played a crucial role in students’ interest, engagement, and science identity. Students emphasized the teacher’s manner, respect, understanding, kindness, patience, happiness, creativity, organization, and feedback on their assignments throughout the year as the most effective elements. For example, Sarmad said that the teacher “asks students what they need, and work to be a better teacher,” Kia mentioned that “She talks to us in a calm manner and she is kind and understanding which most teachers aren’t” and finally Max said,

The things that I wish all teachers would do that this teacher does is to be patient and happy. Patience helps me, not when someone is immediately telling me what I did
wrong and giving me the right answer. Good teachers like this teacher would talk me through the assignment and point out some things that I could easily fix. Also, I know teachers have bad days, but if the teacher just shows that she is excited to see us and shows that she wants us to learn to make her day better, that would help a lot. If one suffers, everyone suffers and that is not a good environment for people to learn in.

Therefore, the data showed how students’ fixed mindsets about different aspects of their life could easily change by improving their skills over time and valuing what they were doing regardless of the result. Furthermore, the growth mindset in the safe and supported environment also motivated students to improve academic performance by inspiration and teaching a positive attitude and professionalism (Figure 21).

![Student's Email to the Teacher Indicating the Effect of Care on His Learning]

**Teacher’s Friendly yet Professional Behavior with Care for Higher Achievement**

Finally, the patterns and codes in the collected data revealed that all the above information regarding respect, care, integrity, and positive mindset leads to the third theme: Promoting higher achievement by teacher’s friendly yet professional behavior by developing a relationship of mutual trust.
Nyhan & Marlowe (1997) define trust as the level of trust a person places in the competency and willingness of others to act fairly, ethically, and predictably is referred to as trust. Leitão & Waugh (2007) also summarize the features of positive teacher-student relationships based on the other scholars’ beliefs (Good and Brophy, 2000; Krause et al., 2006; Larrivee, 2005; Noddings, 2005; Smeyers, 1999) as “mutual acceptance, understanding, warmth, closeness, trust, respect, care and cooperation” (p. 3). As I discussed above, students felt comfortable talking to the teacher and sharing any problems or difficulties that prevented them from doing their work because they could trust the teacher as the goal was students’ learning.

Student survey responses asking them what two specific things the teacher does that help her relationships with students also indicated that students found the teacher helped them as a friend and not as a teacher. Students also agreed that asking them to talk about themselves in class was helpful in this relationship. For example, Juan said, “[s]ome things that the teacher does that help her relationship with us students are when she talks to us and asks us questions about our day and when she tries to get to know us.” Safa also said, “I like when she tells us personal stories and when she talks to us as if we are her friends, not her students.” The influence of such a caring and trustful student-teacher relationship is more supported by Amir (Figure 21) and pearl’s emails (Figure 22), showing that they were inspired to be better students and respectful and informed citizens in society.
Although this finding supports the themes examined in the literature by other researchers in creating a positive student-teacher relationship, it highlights the importance of mutual trust through the consistency of the teacher’s positive behavior and teaching good manners to the students.

**Science Identity Development with Technology, Engaging Activity, and Peer Mentorship**

All the strategies used in this science teaching pedagogy provided evidence of science identity development. According to Avraamidou (2019), science identity is “emotional given that it involves processes of becoming which are associated with visions of self, goals, aspirations, beliefs, and enculturation in specific social, historical, and geopolitical contexts” (p. 337). In other words, science identity is constructed when students are respected, welcomed, and authentic members of their academic community (Zaniewski & Reinholz, 2016; Lewis et al., 2016). In addition, effective classroom settings should improve student interest and attitude toward science. In such an environment, students have a sense of belonging and experience success by having good mentors. The lack of mentor support, academic sexism experiences, low self-efficacy, and frustration in other environments prevent science identity because students are not engaged. Therefore, they avoid learning
science (Kim and Sinatra, 2018). Thus, science identity is identified as the last theme, but it is the central theme in this research.

Carlone and Johnson (2007) proposed a framework to develop a students’ identity that consisted of three components of competence, performance, and recognition. Kim and Sinatra (2018) also added the role of the environment as the fourth component to this “evolving” framework (Carlone & Johnson, 2007, p. 1207). They believe that environmental factors can encourage or discourage developing the science identity (Kim and Sinatra, 2018). The essential features of science identity, including competence, performance, and recognition, was discussed through the main hands-on, technology-based group 3D car activity given in a motivational classroom environment.

According to Hadzigeorgiou & Schulz (2019), engagement in science is the key to understanding, but how to engage students in science has always been challenging. Along with peer-to-peer interactions, hands-on and technology-based activities were likewise the most appealing and engaging classwork for student learning in this study. Furthermore, the collected data showed that hands-on, technology-based group activities provided a fun learning environment that interested the students and encouraged them to share thinking and use creativity, problem-solving and critical thinking skills. In the following paragraphs, I will explain how the 3D car project as a real-life hands-on and technology-based activity enhanced students’ engagement and confidence in learning science.

While a few students in this study mentioned that they were not interested in doing the car project because of their personal interests, most students thought the 3D car project has helped them learn the content because of its nature as a real-life group hands-on activity.
For example, Sofia believed the 3D car project was one of the best engaging and learning methods as they could see the car's performance even though they had designed it digitally. She stated, “we design it and make it come to life with a 3d printer.” This quote supports the effectiveness of real-life hands-on and technology-based activities in learning.

The post-interview responses showed that most of the students had experienced excitement by designing a fun, real-life, group hands-on, and technology-based activity like an engineer. In response to the post-interview question asking, has the 3D car project changed your opinion of yourself as a student of science? If so, how? Do you like science more or less now? Students reiterated that they had the opportunity to work in an environment that supported their learning through peer-to-peer interactions. They also explained that acting like a real engineer, working with technology, real-life, hands-on project, creativity, design, imagination, organized due dates, and positive mentorship helped them stay engaged and interested in learning science. In some other cases, students mentioned that science had become more attractive to them than in the past mainly because they could see its application in their everyday life. For example, Nova said, “the teacher often explains concepts to us by giving real-life examples and life lessons. After she gives real-life examples, I sometimes look for it in my everyday life.”

Most importantly, students showed their expertise in content knowledge by using the scientific vocabulary to explain their answers to the survey and interview questions and indicated the effectiveness of the engineering design compared to past experiences.

Diago

It changed my opinion a little bit as a student and just of science itself. I like science a little bit more now. I feel this way because I really like the hands-on activities, and
this one was the biggest one of the year. I loved how we followed the engineering process and we constantly had to improve, which I really liked, because we were constantly getting the car better and having it perform better, and I really loved that. Also why it was very fun was because I got to work with people that were responsible and helpful, and I really enjoyed working with them. So yes, this project has affected my view of science.

Kevin

I feel like the 3D car project has changed my opinion of myself as a student because I’ve never been good at science, and it has always been a struggle for me, but I feel that this project was very educational to me, and because the project was broken down for me, and we have specific steps for the project, it really helped me learn, and get all of the standards and parts of the project by the due date.

Samir

The 3D car project did change my views of science. It showed me that engineering appears a lot in science, and you can have fun. It is not just numbers and data. I like science a little bit more. The car project let me realize that you can have fun with science. You can chat with your teammates and come up with different, maybe funny ideas.

Although students identified the 3D car project as a helpful group hands-on technology-based activity to learn science, science identity seems to be the common element that led to their motivation, interest, engagement, and learning. In addition, they talked about the factors that made them confident in doing science, such as working as an engineer to improve their project.
In what follows, I explain how enhancing science identity through competence, performance, and recognition in a positive learning environment maximizes students' interest in science learning.

**Competence**

According to Trujillo & Tanner (2014), competence is the ability to understand and apply science topics, skills, and practices. In this study, students explained their work for competence and perceived how engineers practice their profession following the engineering design process in their 3D car journals. Figures 23-28 represent different parts of another group’s electronic journal following the engineering design process (Engineering Design Process, 2014), including

- Asking to identify the need and constrains
- Research the problem
- Imagine possible solutions
- Plan by selecting a promising solution
- Create a model
- Test and evaluate the model
- Improve and redesign as needed

As shown in Figure 23, Brooklyn’s group has considered eight research questions as the first part of the engineering design process. Then, they researched their questions, recorded the website links they had used, added the definitions of the scientific words and what they had found, answered, and addressed their questions. For example, they searched for different types of friction and steps to follow to make an aerodynamic car. Figure 24 shows the “imagine” part of the process, shared pictures of what they have expected to create
at the end of the project matching with real unique cars. This group considered their design aerodynamics and selected the theme of a mouse as a symbol of being fast. They also shared a blueprint of their plan with all the details they thought about building their 3D car. Finally, they shared their 3D design on the Tinkercad website (Figure 25) and detailed calculations of all the testing trials, as shown in (Figure 26). Even though this group thoroughly researched all aspects of their car, the printer’s residue on wheels prevented the wheels from being completely round. Yet, the group tried to sand the wheels to make them round and tested them before using the premade wheels ultimately. As illustrated in Figure 26, the average speed of their car was 0.32 meters per second, faster than the car with the premade wheels. Finally, they explained how they improved their model by putting tape around the axles to prevent sliding and testing their car on smooth surfaces to minimize friction (Figure 28).

Likewise, other groups also applied the scientific concepts during the engineering process to show their expertise was based on their interest and skills to make an optimal car. This group did not need to improve their model because they planned very well with critical thinking and practical design at the beginning of the project.
Figure 23: NGSS 3D Car Group Electronic Journal
Engineering Design Process:

Ask

- What type of power should we use for our car?
- What shape should our car be?
- Is the car going to be hollow?
- What could change the speed and cause our car to slow down?
- How will the different types of friction affect our car?
- What surfaces reduce the friction?
- How can we make wheels on our car?
- What size should the wheels be?

Research

Chassis is similar to a wing or aircraft shape in planes, except it is mounted upside down so it creates a downward force instead of a lift.

https://www.makespace.com/make-a-battery-powered-car/ This website shows us how to use a motor.


http://www.physicscentral.com/OI/Series/the-physics-of-making-how-deep.html This website tells us how tall a wall should be.

https://www.physicscentral.com/OI/Series/the-physics-of-making-how-deep.html This website shows us that friction is caused by rough surfaces the table. It also tells us that the lighter our car is the less friction it will have.

Figure 24: NGSS 3D Car Group Electronic Journal
Figure 25: NGSS 3D Car Group Electronic Journal

We choose this design because we think it will be aerodynamic and have a low amount of friction. We want our design to have these features because they will help our car have a higher velocity, which is one of the goals of this project.

- **Wheels:** 5cm in diameter
- **Axle:** 4cm long
- **Length:** 15cm
- **Width:** 4cm

**Velocity:** The speed of an object in a specific direction

**Displacement:** The movement of an object in a specific direction

We plan to send our car down a hill. This means we will be using gravity as our source of power.

**Gravity:** A universal force that pulls matter towards the center of Earth

We plan to use gravity to power our car.

Tinkercad Link:
https://www.tinkercad.com/things/TopGtrThzMYE-smashing
https://www.tinkercad.com/things/0CodfX2T_W
https://www.tinkercad.com/things/V7StUxMmpGq3TYYwwV3O95nCy
We want to reduce the amount of kinetic friction in our car as it will move as fast as possible.

**Rolling Friction:** The friction between two objects that are rolling past each other.

Rolling friction will be present in our car due to the car's wheels moving along the track. By minimizing the rolling friction, the car will move more smoothly.

**Fluid Friction:** The friction caused by an object moving through an air or water.

The car moves through the air, creating fluid friction. To minimize fluid friction, the car must be more aerodynamic.

[Website1](https://www.instructables.com/Create-Wheels-and-Air/) This website shows us how to make wheels for our car.

[Website2](https://www.youtube.com/watch?v=FR-6U6E5CA) This video demonstrates the use of small and large tires.

**Motion:** The movement of an object.

The car will be in motion for the trial. In order to move the car, an unbalanced force needs to be applied. We will be using gravity to power the car.

**Speed:** How fast an object is moving (Swift)

The speed of the car depends on many factors. How much force is being applied, the amount of friction present, etc.

Figure 26: NGSS 3D Car Group Electronic Journal
Our car remained at rest until we acted upon it by letting it go down a hill; then it stayed in motion until friction caused it to slow down.

**Newton’s Second Law of Motion:** Force = Mass \times\text{ Acceleration}

We wanted our car to accelerate more, so we extended the ramp. The extension of our ramp allowed more force to act on our car.

**Acceleration:** The change in speed or direction of an object.

### Ramp and Track:

We decided to use the tire and the poster board because we thought they would produce low amounts of friction. The pole sticks noted the track mark every meter.

### Videos

- Video 1: Our wheels
- Video 2: Our wheels
- Video 3: Our wheels
- Video 1: Store bought wheels
- Video 2: Store bought wheels
- Video 3: Store bought wheels

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**Figure 27: NGSS 3D Car Group Electronic Journal**

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**Improve**

When we first printed our car, the wheels were slightly elliptical, our solution was to sand the wheels down as well as some of the rougher parts. We are still unsure if our wheels will be round enough to carry our car down a ramp but we will be testing the car with both our printed wheels and the pro bought ones.

We are planning to test our car on a number of different surfaces that we feel will produce less friction. One such surface will be a smooth paper board as well as some tables. If one of our surfaces does better than the others then we will continue the trials using that surface.

We tested with the premade wheels but they were sliding around so we put tape on the axles to keep it from sliding.

We experienced setbacks with our wheels so we extended the ramp so that it could gain more distance.

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**Figure 28: NGSS 3D Car Group Electronic Journal**
After this project, a post-interview question regarding how confident students were in the engineering design process demonstrated that 83% of the students felt highly confident, and 13% felt fairly confident. Only 4% remained not confident.

The negative responses mainly were related to students’ interests but still mentioned liking the creative design. For example, Shadi said,

I am not confident because I still don’t like the engineering process to the car, I would be able to explain it to someone younger than me, and I am sort of excited because I want to see how much more creative it can get.

On the other hand, Martha had a mindset that was still on the traditional teaching and learning because she thought she should memorize the engineering design process instead of learning it.

Martha

I am not as confident in the engineering process as I would like to be. I understand the basic idea and could most likely teach it to someone if I had a paper to remind me. If I do not take the time to specifically memorize something I will not remember, which makes it difficult to teach the process. I’m pretty confident to start NGSS I believe that I have enough understanding to make it through.

However, real-life, hands-on, and creative design was rapidly used in most positive responses. Again, students even used the scientific vocabulary learned during this unit in their responses. Below are some examples of student responses to the post-interview question. To better evaluate students’ confidence in their content knowledge, the question asked them if they could teach the content learned through the engineering design to someone younger than themselves.
Adel

I am more confident in engineering design after doing this project. This assignment helped me understand more about momentum, velocity, and motion because I was able to experiment with engineering. I would be able to teach this information to someone younger than me.

Mateo

Yes, I am more confident in the engineering design process because I can now better visualize the different steps and when I do assignments I can tell which part of the engineering process each thing would be in. Yes, I can teach someone younger than myself. I am pretty confident in starting NGSS science class next year because I feel like I have learned a lot and that I am well prepared.

Rebeca

Yes, my confidence went way up because I didn’t think we were going to be able to make a car out of plane blueprints. I was so excited that when I got home I told my mom right away. Now I feel like I can design a great looking and great working car.

Brady

Yes i am very confident on the engineering design process after doing this project because i now know how exactly how to go through it by each step and understanding the science behind it. I 100% can teach it to someone younger than myself because i learned about all the definitions of all the science with the engineering design process.

I am confident on starting my next Generation Science Standards science class next year because i believe and know that I have learned so much this year and think that i have gained a lot of knowlange [sic] that i thought i didn’t know i could’ve learned.
Although the above data explains students’ positive feelings about their learning, some students shared their expertise in the content by using scientific vocabulary like Adel.

**Performance**

Performance refers to the social acts of science practices in the public realm and science culture, which most commonly includes proving competence to other scientific community members (Trujillo & Tanner, 2014). In emphasizing the peer-to-peer interactions, student data revealed “performance” enhanced their confidence in their ability to conduct science on their own (Hunter et al. 2007, Hazari et al. 2010)

Some students typically ask that they do not present individual projects to the class. Still, in this study, all the group members were willing to participate in the 3D car project presentation. Some groups even asked the teacher to give their presentation sooner than the deadline. Below, Martin’s comment shows that he believed presentations were another most engaging class activity because of socialization or peer-to-peer interaction. He wrote, “[t]he projects I find most engaging are the presentations… It required people to talk to the class for a while, so it was pretty engaging.”

Even though some students were online for the presentations, they presented virtually. Since students followed the engineering design process, as shown in the figure below (the figure is missing), each person explained a specific part. First, every group explained the individual’s responsibilities and briefly talked about their jobs in the time logs. Then, they presented their electronic journal as a PowerPoint following the engineering design process. In general, they shared their questions and how they developed solutions and planned for their approaches. Finally, they shared how they assembled pieces, tested, and evaluated their car based on modifications and calculations.
An example from the data reinforces the student’s interactions and learning during presentations as well as the student’s interest to perform. As mentioned above, modifications and improvements were a significant part of the engineering process. Therefore, students needed to refine the design to enhance their 3D car projects. For example, a group added more weight to their 3D car to accelerate it down a ramp (Figure 29) and make it roll faster. Making this decision shows how students applied their scientific solutions to improve the car project. Sharing and presenting solutions or steps that the group tested to enhance their project was also helpful to those who had not thought about such possibilities. In some cases, the audience students also shared other options that could have been helpful. For example, during this presentation, the group shared a video of their car testing and mentioned that:

Dylan then took the prototype home and tried to test it on Thursday, April 15, and did not have much success. He could not figure out how to make the cargo with the rubber bands, and the wheels were slipping out from under it. He then tried again on Sunday and had more luck this time. He tested different things, such as the weight, and added more, the friction of the wheels, and a ramp.

Ethan from the audience shouted to his group partners that “guys, see, I told you to add more weight to our car. You did not listen to me.” Savannah also shared her suggestion with the presenters and said, “you could use rubber bands on the wheels like us.” Noah, the third student in the class, replied, “we used wax paper for the ramp, and that could work great for you too.” When another student raised her hand to talk, Liam, one of the presenters, said, “comments and questions after we’re done.” Then he proudly replied, “I am going to present next!” Liam’s quote is an example to demonstrate how interested students were in presenting their scientific knowledge and skills utilized during the project.
Recognition

Finally, students’ data showed recognition as the third component that enhanced students’ confidence and science identity. Recognition happens when a student perceives himself as a science person (Carlone and Johnson 2007) and how scientists use their knowledge to solve real-world problems (Anthony et al., 2017).

Although developing confidence through acting as an engineer has been discussed in other parts, other elements that enhanced this capability will be analyzed in this section. After each group presentation, the teacher appreciated the students’ effort to show them that she recognized their hard work and gave students a sense of accomplishment to increase their confidence, as recognition was suggested in Willis (2007). The teacher also highlighted features of their work, such as excellent cooperation, organization, their explanation of how the forces and motion concepts applied to their project performance and design and noted that they put the scientific units next to their answers.

Moreover, throughout the school year, when I checked the student’s work at the end of the class, I stamped their work with some positive notes such as “Good job,” “Excellent,”
“Supper,” etc. Besides that, I told each student, “you are the best,” “you are awesome,” “thank you for being such a wonderful student,” or “you are my favorite student.” Dominic asked me why I tell everybody that they are my favorite students? My answer to him was that all my students were my favorite students. I look at all my students as they are my children. Students mentioned that they felt “very special and confident” when I gave them these compliments, especially low performing, and defiant students. They also said they tried their hardest to work and participate because their effort could be seen and recognized no matter how well they did it. However, if some of their answers were incorrect to some daily work questions, I still gave them positive words and full credit, and I only told them to think about those questions again. In most cases, students fixed their answers or tried their best to find correct answers to make the teacher happy and receive even more complement for their high-quality work.

Besides verbal recognition, all the students received positive comments on their online work submissions throughout the year. The teacher made positive comments denoting their great critical thinking for student answers and thanked them for their excellent work. Most of the high-quality works were also posted in an exemplary folder on Google Classroom as an example for other students to see and learn (Figure 30).

Figure 32 is also related to the students’ paper airplane activity during the Forces and Motion unit. As shown in the figure, two open-ended questions asked students to share their thoughts and understanding of the day’s lesson. Navid showed a great understanding of the day’s lesson and applied his knowledge to a real-life example by explaining his reasoning using scientific concepts.
Figure 3 shows that the teacher recognized, mentioned, and appreciated students’ high-quality and organized work. Students received extra credit for submitting high-quality work, such as putting all the scientific formulas, correct calculations or thoroughly explaining their answers and keeping them well organized, as shown in Figure 32.

Figure 30: Teacher's Positive and Motivational Comment on Student's Assignment

Figure 31: Teacher’s Thank You Comment for High-Quality Work
In Figure 32, the student clearly explained all the components of Newton’s three laws of motion. She also used simple but informative pictures and included Newton’s second law formula to teach this topic to someone younger than herself. Students also highly rated the impact of the teacher’s feedback and recognition on their interest and care to learn because they could see themselves as a person of science.

The development of confidence that students see themselves as young engineers is also evident in their post-interview responses. For example, Molana and Fariba mentioned that their science identity improved during the 3D car project.

Molana

The 3D car project made me a better engineer, and made me understand Newton’s laws, and the laws of physics a lot more. I like science more because hands-on activities teach me a lot, and I have tons of fun doing them. This project was fun, and made me learn a lot more, instead of just doing a worksheet. When I was designing the car, we had to research and study to make sure our car was efficient. This project has helped me understand the engineering design process more.
Fariba

I used to believe that science was very complicated and hard to understand. I never thought I could understand it and I would always have to have the teacher explain it to me and then write nonsense down I didn’t understand. Now after this class, I like science more because I see how it works and understand it. I can determine whether something makes sense or not by myself.

Finally, Figure 33 is an email from a parent of an ESL student to the teacher signifying that her child taught everything he learned in class to his family at home almost every day during lunchtime. This email implies the impact of students’ confidence in building science identity and how the student saw himself as a science person. The parent email represents that the classroom environment created by the teacher and the activities were suitable for the ESL student to make his science identity by improving his confidence and teaching his new knowledge to his family members.
The analyzed data presented in this chapter revealed the importance of science identity in a positive learning environment through competence, performance, and recognition. In addition, the role of narratives and real-life examples to help students internalize and transform new science information by forming new cognitive structures, which results in new understanding, has been discussed. Analysis of the collected data also revealed the students’ ability to improve their scientific knowledge and skills through NGSS by working in group hands-on and technology-based activities. Finally, the significance of the teacher’s constant support and role model to impact students’ attitudes, values, behaviors, and academic performance has been examined and presented.
CHAPTER V: CONCLUSIONS

This chapter presents the conclusions and implications drawn from the results. In addition, I will discuss the limitations, recommendations to in-service and pre-service teachers, and the implications for future research.

This self-study action research sought to investigate, understand, and reflect on the learning environment and practices that enhance teaching and learning in the classroom using a constructivist NGSS-based pedagogy. I found a strong relationship between the collected data in this research and the result of other researchers discussed in chapter two. Through data analysis, four themes and a subtheme were identified. In the following paragraphs, I will discuss the conclusions and implications based on each identified theme. I will then share my recommendations to in-service and pre-service teachers at the end of each theme. Finally, I will talk about limitations and suggestions for future research.

Theme 1: Inspiring Students with Teacher’s Narratives and Real-Life Examples

At the beginning of this research, only about half of the students thought that doing well in science had any importance in their lives. However, over time, students valued science more when they learned about its significance and application worldwide through the teacher’s real-life stories. While the collected data indicated that the students were interested in science for various reasons such as job interest, family interest, understanding the surroundings, or doing well at school, they valued science more when they learned about science on a large scale. For example, the global crisis, the Covid-19 pandemic, was a great living example for the students to feel and understand the value of science in life. As a result, 80% of students indicated that they need to learn science to keep the U.S. a global leader in science and technology. This rate shows that such examples light up students' attention and
that they care to protect their country by learning science. Real-life examples and narratives were valuable teaching strategies to maximize students' interest in science learning. It also allowed students to visualize the importance and the application of science in real-life situations. As a result, students appeared to care more about their academic education and critically thought about their lives and careers to plan their future.

In this study, narratives and real-life examples effectively improved students’ engagement, science concept learning, and retention. The result of the post-tests on the unit of forces and motion indicated that narratives made some abstract science concepts more informal and exciting for learning with regard to the reality of the content. The data analysis also revealed that most students developed an adequate scientific understanding of forces and motion using real-life examples and narratives. The survey and interview data also supported this finding. For instance, almost all the students indicated that narratives and real-life examples engaged their learning and helped them comprehend and make it easy to remember principles because they could see the real-world application of the scientific concepts. Perhaps more engagement and learning via narratives were related to individuals’ curiosity, as all of us are eager to find out more about this world. According to Hu et al. (2021), narratives in science teaching maximize student engagement, curiosity, and the acquisition of new knowledge. There are two modes of thinking; one is the sociological mode which abstracts information from its context to process it. While on the other hand, the narrative mode is context-dependent and is based on situation-based evidence. Despite traditional teaching that mainly focuses on facts or a timeline of discoveries, stories about science and scientists can have significant positive affective effects on students, thus inspiring them to pursue more subject-specific learning (Hu et al., 2021). Furthermore, the narrative mode of
thinking is commonly recognized as the default mode of the human mind, bringing structure to reality and functioning as the underlying foundation for memory (Dahlstrom, 2014, as cited in Hu et al., 2021). Thus, to prepare narratives for teaching a science topic, teachers should consider the background knowledge or the misconceptions among the audience (Hu et al., 2021). Additionally, I believe that teachers need to understand the fundamental focus of science teaching should be engaging and exciting students with accurate scientific information.

On a typical day of teaching, I start the class by writing a few questions related to the day's topic on the board as the bellringer/warmup. I also display some pictures, charts, or definitions of the keywords on the Promethean board so that students can connect their background knowledge to the lesson of the day. In addition, to encourage students to answer all the warmup questions, I ask them to explain the answers if someone younger than themselves would ask them those questions. Next, I ask students to write in simple language how they might present the concept to someone younger than themselves. This task can help them think critically and connect their background knowledge to the day's lesson. Then, I let the students discuss and share their answers with their peers as I walk around the classroom to stamp their answers in their science notebooks and give them positive and motivational comments. The positive comments on students’ thinking given in their science notebooks provide immediate feedback for the students. It also helps me assess their level of knowledge for teaching the whole class.

Finally, students share their answers with the class by raising their hands for each question, and I guide their thinking through questioning strategies to the correct answer. During the class discussion reviewing the bellringer answers, instead of approving or
disapproving students’ responses, I question them with real-life examples or narratives to use their prior knowledge to understand the topic better. For example, during the data collection period, I asked the students about the definition of speed; most students explained that speed is how fast something goes. At that point, most of the students did not know the formula of speed. Then, I asked them to tell me about the speed limits at the school zones. Almost everybody stated 5 to 25 miles per hour. Next, I asked them how the units of miles and hours are used in this instance. In doing so, students mentioned distance and time. That was the “aha moment” for them realizing that the formula for speed is distance divided by time.

According to Zhang & Probst (2016),

Unlike in advanced physics courses, many concepts in introductory physics can be related to everyday life experience. Therefore, they can be introduced by tapping into such a vast intuitive knowledge base. Specifically, the automobile is an excellent example for many concepts in Newtonian mechanics (p. 3).

Moreover, based on my teaching experiences, students often do not see the application of math and science outside of school. Hence, sharing real-life examples throughout my teaching allowed students to see where and how we use these subjects in our lives and helped them deeply learn each topic in science by remembering the examples. For example, I reminded them about the time they started learning multiplication. For sure, many of them have asked why they should learn multiplication tables because they could not see the real-life application by then. However, as they got older, they could easily see how valuable multiplication is in everyday life. Consequently, I explained that studying science also allows them to become better critical thinkers and problem-solvers both in life and in their future careers (Sargent Jr, 2017).
The warmup strategy in my classrooms had a brainstorming effect on students while sharing their knowledge and experiences with their peers for the best answer. In addition, using narratives and real-life examples profoundly engaged the students. Those shortened stories and real-life examples allowed students to think critically, construct meaning, and gain more understanding by connecting the new information to their background knowledge.

Besides teaching conceptual knowledge in science through narratives, my students also learn how to interact in social settings when learning. They also come to realize that belonging to a community of learners is essential for comprehending complex topics. I do this by helping them understand the role that sadness, fear, anxiety, joy, shame, anger, kindness, and even hatred are undeniable and natural human feelings that affect learning (Hacker, 2017). For example, I used narratives as life lessons to teach students about these human characteristics and deal with each feeling appropriately. Students discussed and concluded during the school year that we should learn from history and other people’s lives, how we want to live and which emotions we want to be highlighted more in our lives. The path that we choose should help us grow based on our goals, and we should not live “randomly” day by day.

This kind of discussion can lead to topics related to diversity. For example, unlike in many other countries, we can learn about other people’s cultures from different parts of the world by simply becoming friends. Instead of being shy and refusing to ask about their culture, beliefs, and values, I taught them to show interest in asking and sharing their views respectfully because all of us have a unique and beautiful culture. Therefore, providing such a safe classroom environment where students could exchange their thoughts and perspectives helped them broaden their views and understand that my role as the teacher was to teach
them how to be happy, healthy, polite, and informed citizens. Such a classroom environment can also significantly enhance students’ confidence and academic work (Goleman, 2005).

Therefore, teachers should not rely only on parents to teach their children about life and good behaviors. Instead, students’ life-long goals should be teachers’ primary objectives and teach them about all aspects of life, which also improves their responsibility. Finally, using the prefixes of Ms., Mr., Dear, or Dr. with students’ names provided the students extra attention and respect and had a motivational effect as students could see that the teacher had high expectations of them. Hence, they tried to show their capabilities by putting more effort into their work and behavior.

I recommend in-service and preservice teachers first understand the topic and use narratives with accurate and true scientific information. Otherwise, they lead to misconceptions. In addition, use engaging questions for the bellringer to inspire students and let them be curious to find the answer. The questions should be designed so that the solution is not immediately found so that students’ critical thinking is challenged. More importantly, the teacher should further teach them about the topic by asking questions that require broader thinking for better responses and deep learning. Finally, using students’ names with their permission in the narratives makes the lesson even more personalized.

Finally, teachers need to minimize students’ stress and anxiety and let them learn the content with joy and happiness. Understanding that students are at the learning stage in all aspects of life more than adults can help educators guide learners better. Therefore, by sharing experiences, teachers can teach students time management and work prioritization so that they can learn without the teacher putting pressure on them. A neurology researcher
Willis (2007), also showed the effectiveness of a joyful education on focused attention, which results in learning. He revealed that

Classroom experiences that are free of intimidation may help information pass through the amygdala's affective filter. In addition, when classroom activities are pleasurable, the brain releases dopamine, a neurotransmitter that stimulates the memory centers and promotes the release of acetylcholine, which increases focused attention (p.2)

**Theme 2: Investigating Phenomena and Solving Problems by Doing Science through NGSS**

In general, because of Covid-19, the online school was an excellent chance for the teachers to learn more about technology and technology-based activities, an effective learning method for 21st-century students. It also allowed students to do more of their schoolwork with technology. That was a great transition from traditional teaching and learning to NGSS-based pedagogy with no notetaking but more teamwork and project-based learning.

Moreover, one of the benefits of online student collaboration was learning how to work with other people remotely. In addition, this remote collaboration was great practice for students who might continue their careers in jobs such as academia. Therefore, offering technology-based projects that students learn about partnerships and corporations can better prepare our students for their future.

This study showed that the NGSS lessons encouraged students’ curiosity and interest to solve their scientific questions. For example, during the class discussion regarding friction, the students tried to name all different types and ways to oppose friction to increase the speed
of their 3D cars going down the test ramp and consequently going for a longer distance. Some of the students even stood up and raised their hands to be the next person to talk in class and share their ideas. Some others searched online to ensure they had not missed any types of friction and discussed their new findings. A student used his science notebook and a pencil sharpener to model the car and the ramp to test the best angle for faster speed.

Therefore, the entire process of NGSS made science topics easy for students to understand as contrasted with memorizing or following a textbook to use the information once to complete the project. Students also improved their scientific knowledge, critical thinking, and problem-solving by sharing their learning and reasoning with their peers in groups and making alternative decisions to enhance their work and learning instead of memorizing the scientific information.

Additionally, NGSS lessons provided various opportunities for students to engage in creative design (3D cars), which influenced their interest in understanding scientific concepts. Finally, collaboration based on individual student expertise and comfort levels maximized group work outcomes since each student played an important role in completing the engineering project. For example, students took on different responsibilities such as organizer, designer, quality controller/tester, builder, scientist, etc., which led to a higher level of thinking and working. Although they took on these individual roles, it was clear that all students could apply their scientific expertise in designing the 3D car using the Tinkercad website, evaluating their 3D cars, and analyzing the outcome simultaneously in a fun, professional, and supported environment. The result of the pre-and post-test and the outcomes of the 3D cars support this finding as seen in the pre-and post-test Figure 16: Comparison of the correct rate in pre-and-post-test.
Breaking down the unit of forces and motion into smaller sections for more in-depth lessons aligned with NGSS through 5e lesson plans allowed for deeper conceptual learning, retention, and broad applications of knowledge by frequently assessing students' learning and scientific literacy. In this process, the teacher was only a link between students and the content, disciplinary core ideas, and crosscutting concepts and facilitated students’ learning.

Subtheme: Promoting Innovation and Creative Design while Applying the Content Knowledge Following the Engineering Design Process

The engineering design also improved students’ ability to conduct a scientific inquiry during the construction of the 3D car project (Bybee 2009). The reason is that the engineering design process encouraged the students to think and act like scientists and engineers—rather than simply memorizing the content or just developing specific skills. The goal of the NGSS is to allow students to develop an understanding of the nature of science and engineering to overcome significant socioeconomic and environmental problems that they will face in the future (Next Generation Science Standards Lead States, 2013). Therefore, following the standards, students should comprehend and use the engineering process in their daily work.

The engineering design process, which engineers utilize to address challenges, showed a valuable tool to challenge students' creativity, thinking, and problem-solving skills while applying the scientific concepts in their unique design. The data showed that the students tested their reasoning and talent through the engineering design, used their knowledge, and addressed the problems while sketching and designing the 3D-car project for the best outcome of going fast and far. According to Eide et al. (2002), design is simply a “structured problem solving activity” (p. 55). In light of this view, students improved their
problem-solving, creativity, and critical thinking skills during this process while applying their scientific knowledge to their design. Students also understood the scientific concepts and laws in designing the 3D car project for the utmost performance.

Most importantly, they improved their design, considering factors of superior design, high performance, and low cost. Innovation and improvements were the fundamental part of engineering design as they encouraged students to combine their knowledge and creativity and learn from failure. Figures 34 and 35 represent the students’ unique 3D cars with different power systems, including wind, gravity, balloon, circuit, baking soda, and vinegar.

![Figure 34: Student’s 3D Car Raw Designs before Assembly and Paint](image-url)
With its many routes to solutions, engineering design helped students of various capacities feel accomplished since they all had a feeling that they had accomplished something somehow. This truth explains that engineering design, with its inherent motivating power, can boost motivation and expedite learning if applied effectively. Perhaps engineering's ability to attract and thus motivate has given it its penetrative educational influence.

During online collaboration to design their 3D car project, communication was the only obstacle students faced. Otherwise, they enjoyed and showed significant science learning through technology and group-hands-on activities. As a result, they also recommended this project for future students. However, the communication problem can be
improved if teachers check and ensure that the students have their group partners' multi-contact information such as phone number, email, and Google chat.

Finally, I recommend that the in-service and pre-service teachers provide a high-quality science education by implementing NGSS into their teaching. Choosing helpful real-life hands-on and technology-based activities can promote active participation by creating linkages to students' interests and college and career objectives. First, however, it is crucial to learn how to read and use NGSS standards. I highly recommend the YouTube video series by Paul Anderson (2013) for an overview of the development of NGSS.

Allowing students to work with their friends and yet using a strategy to group them based on varying knowledge and skills is crucial for learning and completing the activity on time. Successful teamwork happens when each member fulfills their respective responsibilities. Therefore, choosing a leader with confidence, good communication skills, and dedication is essential. Finally, the group leader needs to check the progress of everyone’s work weekly or daily to ensure the project's quality and flow. The teacher should also put different deadlines for different activity parts to constantly assess their learning and monitor their progress.

Although students found technology-based activities interactive and educational, teachers need to consider that our students are not entirely familiar with NGSS. As a result, they might have a misconception about not being taught well in class. Thus, educators need to clearly explain the difference between traditional and NGSS based teaching and learning to the students and parents at the beginning of the year. After all, administrative support and understanding of the new teaching method by NGSS are crucial for successful teaching.
Theme 3: Promoting Higher Achievement by Teacher’s Friendly Yet Professional Behavior by Developing a Relationship of Mutual Trust.

The data also supported the importance of a positive student-teacher relationship in students’ engagement, performance, and success. The essential component of such a relationship strongly relied on the teacher’s consistency in her supportive and caring behavior. The students acknowledged the teacher’s consistent behavior to respect them, support them and care about their learning had motivational and engagement effects.

This study indicated that students want to see that they are welcome in a classroom, and the teacher is interested in knowing how their day went. It was very appealing to greet the students by calling their names at the door or even entering the Google Meet. Not only receiving respect but also learning about respect and professionalism helped the students to understand the importance of good manners in life. Learning about good behavior and professionalism also improved students’ effort in classwork as it encouraged them to be more professional and responsible. It also enhanced the classroom environment to be more productive with more engagement and fewer distractions. For example, I realized that some students entered the class feeling bored or not paying attention to me as I greeted them. Therefore, to improve their mood and behavior, I asked them how they would feel if they entered an airplane and saw that the flight attendants were tired, not smiling or greeting the passengers? They replied that they would get mad and complain to the airline or no longer purchase tickets for that airline. Then I told them whenever I come to the door or open the Google Meet, I feel like a flight attendant. I greet them with a smile and full of energy and wish the students a great learning time. However, I expect them to enter my class with the same feeling and show me their excitement for another day together to improve our
knowledge and behavior. I also need to receive positive energy from them for better teaching.

As a result, most students entered the class with a more positive demeanor on the following days. Some students who were talking with their classmates when they entered the class exited again soon after realizing they missed my greetings at the door and walked in again, showing me their smiles, kindness, and happiness.

Another effective strategy was daily asking students about their day, schoolwork, and life in general. Hearing their voices and letting them share their life experiences every day, like friends who talk about their thoughts and feelings, strengthened my relationship with the students. In addition, this approach created more trust between the students and the teacher. If there was anything that I could help with, I always provided them with advice and suggestions or positively shared my personal experiences to teach them how to overcome their problems. Otherwise, I reminded them that they are 21st-century students and have many abilities and skills, such as critical thinking and problem-solving skills, to solve their problems by making the best decisions. Listening to their concerns and reminding them about their capabilities supported them and improved their temperament to think better and decide more effectively.

Besides providing various activities to address the needs of all types of learners, I sent positive comments to students with missing or incomplete assignments to encourage them to complete them. For example, if they were absent, I sent them a message and asked how they were doing, if they needed any help, and sometimes offered them extra time to submit their work to make them comfortable instead of making them nervous. This strategy also helped students feel more responsible, and in most cases, they finished and submitted their work quickly.
Moreover, instead of listing their wrong answers and deducting some points, I first mentioned solutions for grading their assignments. I then talked about their wrong answers and how to avoid making those mistakes again. I also did not deduct any points, even for a few wrong answers. Yet, I told them to see me for more help if my explanation was insufficient. As a result, students finished or fixed their answers and resubmitted the work to show their understanding and interest in learning. Students did a few assignments or activities for each topic, and I only deducted points if they made the same mistake for the second or third time. Still, I allowed them to fix their answers and write a paragraph teaching it to someone younger than themselves for full credit. This strategy significantly helped students learn the topic and retain the information.

The teacher’s positive comments on students’ work also encouraged them to continue doing high-quality work to be more praised by the teacher. This study indicated that students cared more about their learning when the teacher always had understanding for personal problems that led to late work and even showed support for doing the assignments and learning. In addition, establishing a friendly relationship between students and the teacher created mutual trust, care, and respect that allowed students to practice professional behavior. This strategy also significantly impacted classroom management as students learned how to regulate their behavior professionally. Furthermore, learning in such a classroom environment also enhanced students’ growth mindset. During this process, students focused on improvements and understood that learning is not an inherent talent; instead, their effort is needed to enhance their abilities and professionalism.

Although not everybody sees success in higher education, I wanted my students to learn how to work hard and keep their opportunities open later on if they decide to continue
their education for higher degrees. Therefore, this belief made me prepare my students for higher goals than one school year.

Therefore, in-service and pre-service teachers need to consider that typically, teachers grade students' work, tell them mostly what they got wrong, and deduct some points. It is usually not very common to post a positive comment if a student has many mistakes. If we think that someone mentions and constantly reminds us how weak and wrong we are in something we do, it will minimize our confidence, motivation, and energy to improve. On the other hand, hearing how capable we are of doing things no matter how many mistakes we make will double our motivation, care, enthusiasm, and time for learning. That also allows students not to feel shy about their mistakes.

Furthermore, teachers typically hear many excuses for students' lack of work, and it is sometimes difficult to determine if their reasons are real or not. It is easy to judge based on students’ overall performance in class. However, in my classes, the truthfulness or falseness of students’ reasons was not my priority. Instead, I valued students who approached and asked for help to do their work to learn. Some teachers might think that students will take advantage of such a strategy and not do their work on time. I agree with this thought if students receive this opportunity without other essential teaching elements discussed in this study, such as a sense of belonging or a positive teacher-student relationship that leads to mutual trust.

Moreover, I think adulthood life is more complex and challenging. Therefore, it is crucial to positively prepare our students to deal with more challenges in their lives. One of the best ways to understand this is to put our feet in their shoes and see how we expect others to treat us. For example, when a student was gone for a sports competition and spent many
hours driving home and was overwhelmed with many missing assignments from different classes, why should I refuse to accept their late work or deduct points for late submissions? Instead, I will provide more opportunities to help the students to learn. Of course, there might be extra work for me, but it will help the student see herself as capable, interested, respected, and recognized by getting good grades. Whereas in the opposite scenario, not doing the work because of not having the chance of having a minimal opportunity to do their missing work might lead to a succession of events such as being scared of the teacher, getting bad grades because of not learning, possibly being disciplined by the parents, and finally hating the subject and the school in general. Although these students are capable, this undesirable attitude and experience might negatively impact their lives and future career. Hence teachers should always show their care and how excited they are to teach by their actions.

In-service and pre-service teachers also need to consider that most parents are usually busy and tired when they get home from work. It may be difficult to constantly show kindness to their teenagers or acknowledge students’ daily schoolwork achievements. Typically doing schoolwork well is one of the minimum requirements every parent expects from their child. Therefore, recognizing students’ work daily, at least by teachers, makes a considerable change as students yearn for attention and recognition no matter how old they are or how significant their achievement is. Identifying and recognizing students’ work is a minimum job that every teacher can do daily and noticeably impact students’ confidence and academic performance.

**Theme 4: Fostering Science Identity**

In data analysis, developing a science identity was identified as the core theme applying to every other theme and sub-themes identified in this study. Science identity was
shown to be one of the main principles for students’ confidence leading to their interest in learning more science. The data showed competence and performance by doing group hands-on, technology-based activities and constant recognition in a safe and supporting environment were influential factors enhancing students’ science confidence and eventually leading to a science identity.

Students felt motivated when asked to contribute based on their capabilities and knowledge. In this case, they were not compared with others but had to present their unique talent and thinking based on what they had learned in science. Thus, students created an intellectual environment by helping each other understand the content without embarrassment since everybody was supposed to support each other for a common goal.

The engineering design acted as a great tool in creating the intellectual environment by encouraging the students to innovate a unique 3D car by applying the content knowledge, improving the design, seeing themselves as young scientists (Kim, 2018) or engineers, and developing a higher science identity. In addition, science identity allowed students to build more science literacy by researching and reminding each other about the scientific facts and laws that needed to be considered for the best outcome.

Recognition was also a valuable strategy that significantly impacted students’ confidence and identity by recognizing students’ talents and efforts, encouraging them to work harder and be better students. This strategy also improved ESL students' science identity by maximizing their confidence and participation.

Stamping students’ daily bellringer or classwork was another excellent strategy for recognition. Sometimes, students raised their hands, reminding me that I forgot to stamp their bellringer answers. If I did not show my enthusiasm while commenting on their answers,
they would typically mention it later. For example, they showed me by taking a deep breath of relief if I enthusiastically commented about their work the next day. Students have often said that they have thought their answers did not meet my expectations, which is why I did not show my excitement and recognition. Finally, to review the answers to their daily assignments, I asked a volunteer to answer the first question. Then they picked the next person for the next question. That way, more peer-to-peer interactions minimized the stress of being called up by the teacher. Instead, it provided a more fun class environment for students to participate and learn from each other.

The result of grouping students based on mixed abilities, yet working with their friends, also indicated that students’ interactions helped them improve their science identity by encouraging them to learn because of their interests and capabilities. Furthermore, this strategy did not put all the high-performing or low-performing students in one group. Through peer teaching, students could also better learn from each other (Assinder, 1991). Finally, the outcome of their group project revealed the high accountability of each group member as they used a time log, showed what they had done, and explained what they learned while presenting their final project in class (Johnson & Johnson, 1999).

Finally, Figure 36 represents Zara’s electronic thank you card to the teacher at the end of the year. Her note aligned directly with all the results found in this study. She indicated that she had fun learning science through group work and activities like the 3D car project. In light of science learning through science identity, her note also illustrates that the student was confident with the science materials learned throughout the year. Finally, she is prepared to learn more advanced topics during high school because she sees herself as a science person.
Therefore, the results of this study demonstrated students’ receptivity to higher levels of thinking and learning through science identity.

I recommend that in-service and pre-service teachers offer assignments and activities mainly through group work to encourage students to build science identity by interacting with their peers, communicating their curiosity, passion, interest, dedication, knowledge, and becoming active learners. It is important to remember that the teacher’s goal is to help students learn and improve their pre-existing knowledge and not evaluate their deficiencies.
and constantly catch their mistakes and deduct points. Instead, providing them the assurance that you are on their side, ready to assist and support them in improving their learning based on their specific needs, might encourage them to care and put more effort into their studies. Lastly, teachers’ constant recognition of a kind and motivational language can significantly assist this process.

Offering an NGSS-based activity through group work created a positive inquiry and intellectual classroom environment that enhanced students’ science identity. Furthermore, the teacher’s motivation, support, and recognition of students’ work also helped them develop science identity and maximize their interest in learning science. Figure 37 summarizes effective constructivist pedagogy elements that enhance students’ science identities through the learning of science.
Constructivist-Based NGSS Pedagogical Model

Teacher’s Role Pedagogical Approach

Fundamental Classroom Elements

Teacher Narratives with Real-Life Examples

Mutual Trust

Flexible Heterogeneous Teamwork

Teacher’s Recognition of Student Contributions & Learning

Envisioning Future Applications

NGSS Science & Engineering Design Framework

Group Performance & Individual Competence

Increased Individual Engagement & Self-Confidence

Developing Science Identity

Increased Interest in Learning Science

Figure 37: Effective Constructivist Pedagogy Elements for Deep Science Learning
**Teacher’s Role and Pedagogical Approach**

Science and technology are valuable to students, and they are generally interested in these studies. However, to improve their enthusiasm for learning and pursuing science, students must perceive the personal relevance of science. (Basu & Barton, 2007; Carson et al., 2006; Christidou, 2011; Hofstein et al., 2010; Maltese & Tai, 2011; Pressick-Kilborn, 2015; Root-Bernstein & Root-Bernstein, 2013; Rustum, 1990; Turner et al., 2015). In this study, the teacher's role was to create a classroom environment where each student experienced academic success through motivation, support, and peer teaching to see themselves as a science person and to be literate in science. They also needed to see science's daily usage and importance in real life.

**Fundamental Classroom Elements**

*Narratives with Real-Life Examples*

The teacher used the following pedagogical elements to create such a classroom environment. Narratives with real-life examples were used to teach scientific concepts and laws to make them enjoyable and easy to learn. Our data support Dahlstrom (2014) by revealing students' engagement, motivation, and notable concept development and retention through this strategy. The narratives and real-life examples also made science communication easy with students who are not yet experts (Dahlstrom, 2014). The students also perceived science as easy to understand rather than complicated and abstract. As a result, students' engagement maximized their interest and confidence in learning science, and finally, experiencing positive academic achievement led to a higher science identity. The science identity development as seeing themselves as a science person, performing like a
scientist (Carlone and Johnson, 2007), and participating in discourse practices (Brown, 2004) also led students to be eager to learn.

**Mutual Trust and Respect**

Mutual trust and respect developed between the teacher and the students through consistency of the teacher’s positive behavior and teaching good manners to the students. This situation was also helpful in creating an engaging classroom environment. In addition, mutual trust and respect encouraged the students to use cooperative learning (Rotter, 1971) and increased academic motivation and care for high performance. Similar to Walker’s finding (2008), our data showed that the teacher’s warmth, excitement, compassion, frequent praise, high expectations of all, fairness, forgiveness, and responsiveness were the characteristics that helped the students to approach the teacher for any help or guidance for better learning. Moreover, students saw the teacher as a role model to treat others with respect and kindness. As a result, they all created a fun, friendly, and supportive classroom environment that encouraged students to share their knowledge while respecting each other’s diverse forms of learning.

**Flexible Heterogeneous Teamwork**

Furthermore, the heterogeneous flexible grouping throughout the unit of forces and motion allowed students to work with students with similar or dissimilar interests, varying skills, and learning needs to learn from each other in small groups, with a partner, or in the whole class. The teacher also assured the cooperative groups' heterogeneity or varied ability levels based on the pre-and post-tests and classroom observations for the 3D-car project. During the forces and motion unit, this strategy allowed students to actively be involved in learning, especially the ELL students, as they could interact with many different students.
(Tomlinson & McTighe, 2006). According to Davis (1993), when students are actively involved in the learning process, they learn better. As a result of the heterogeneous flexible grouping strategy, students taught each other the content and the skills required for the same goal or the best project. Finally, they all experienced success, became confident about the scientific content and improved their skills. They also gained the ability to take ownership of their learning by accepting responsibility in completing a particular task as a young scientist or engineer.

**Teacher’s Recognition of Student Contributions and Learning**

The teacher’s recognition of student contributions and learning played a crucial role in creating students’ science identities. Charles Taylor describes recognition as a key part of social interaction and developing one's identity and as “a vital human need” (Anderson, 1996, p. i). In this study, recognition was given to the student's quality of work based on their existing abilities and skills. In addition, the teacher gave constant attention by providing positive feedback to help students develop a positive self-image and recognize themselves as unique individuals compared to others (Huttunen & Heikkinen, 2004).

**Envisioning Future Applications**

Finally, discussing possible future applications of science provided opportunities for the majority of the students to connect their lived experience to the practice of visualizing, thinking, and planning how to solve science-related problems. For example, living through Covid-19 was an excellent opportunity to see how my students could link their personal knowledge to scientific understanding so that they could visualize, think as a group, and plan how to interpret obstacles and compare the performance of different countries to save lives.
In other words, they could see the importance of science in daily living, the value of advances in scientific fields, and the use of technology to solve a universal problem.

**Implementing NGSS and Science and Engineering Design Framework**

Implementation of the above elements in this teaching pedagogy created a safe and supportive environment for students to learn science through the NGSS framework and experience a new way of learning to meet rigorous and comprehensive standards (Lee et al., 2014). In this method, students had the opportunity to develop and use models, construct explanations, argue from evidence, observe, and discuss the cause and effect of forces and motion and the types of interaction and their applications in real-life situations. This learning process was based on the three dimensions of NGSS during each lesson. According to Lee et al. (2014), the NGSS raises academic rigor by requiring all students to use science and engineering procedures and crosscutting concepts across various disciplinary core ideas. The three dimensions also improved students’ interest as all could engage with the science activities offered. In addition, students mentioned that they enjoyed learning through NGSS. Therefore maintaining this interest is also crucial as students move to higher grade levels.

Moreover, the engineering design of the 3-D car project following the three dimensions of the NGSS encouraged students to use their creativity and improve their problem-solving skills by taking a responsible role in a group. In this case, all the students needed to ask questions, share their thoughts with their group, construct the car, make arguments, and constantly improve their model to find the best solutions for the most effective outcome while looking for the relationship among variables. In the improvement process, they had the opportunity to test their thoughts and creativity by applying their scientific knowledge in designing 3D cars. According to Turner et al. (2016), “The
effectiveness of the instruction increases when students are more involved in their learning, and engineering design places the student in the role of scientist/engineer” (p. 3). Hence, students learned the core content through self-discovery during the engineering design. They needed to construct explanations, ask more questions, and look for the relationships among the variables to model the 3D car. In addition, the engineering design process encouraged them to take responsibility and enhance their collaboration, reasoning skills, and problem-solving. Finally, it led to deeper learning and perceived competence, as evident in students’ post-test, interview, and survey data.

**Group Performance and Individual Competence**

Students presented their electronic car journals at the end of the project in class. They demonstrated their participation, learning, managing the use of technology, and expertise in the scientific practices of designing 3D cars. Students' presentations also provided an opportunity for all the students to be engaged in scientific discussions. Sharing and teaching the class their unique thinking and design and receiving the teacher’s acknowledgment for their work led students to experience success, build confidence, and see themselves as science people. According to Carlone and Johnson (2007), the three interrelated elements of competence, performance, and recognition are the keys to identifying as a scientist. This study showed that focusing on students' strengths and giving value to them let them see themselves as capable and confident to put effort to learn science and develop a science identity. Offering narratives or real-life examples with relevant scientific activities where students could show their unique talent also encouraged them to become more engaged and participate in learning science and enhance their critical thinking, problem-solving, and science identity.
Finally, this study identified the essential elements of teaching pedagogy that are helpful for students’ engagement and enhance their participation in learning science. The importance of this study is that it shows a combination of all these elements is needed for science teaching and learning. Although each strategy used in this study has been demonstrated effective previously by other researchers, this study explains how to apply them by giving examples to help in-service and pre-service teachers to model their teaching pedagogy for successful students’ learning. Following the suggested teaching pedagogy, teachers can plant positive attitudes toward learning science and a higher interest in commitment to a career in science.

Limitations

Every research study has its own limitations. It is essential to identify the weaknesses and origins of the limitations that influence the study’s result to help readers understand and generalize findings appropriately (Ross and Zaidi, 2019). Several factors limited this qualitative action research. First, the research began online due to the Covid pandemic, but then the school opened as a hybrid. Even though survey and interview data were collected anonymously using Google Forms, only some students had the option to collaborate with their classmates in person. In contrast, others worked with their group partners online through Google Breakout Rooms. Thus, not all the data are consistent because of this opportunity. This study was also conducted during the school's first year to implement Next Generation Science Standards. The teaching and learning through NGSS were new to the teacher, students, parents, and administration.

Another limitation of the study was that most of the students’ data were collected anonymously, following the requirement of the district IRB. Therefore, I could not find the
matching data for each student to better analyze, and I could not confidently say that the sample entirely was representative of the population (Creswell, 2002).

Additionally, there was a potential for a non-response error. This type of inaccuracy could have been produced by those sample members who did not respond to the survey questions due to a low response rate. As a result, individual student replies were not always representative of the target community as a whole (Dillman, 2000). Furthermore, the study was constrained by the fact that it was conducted primarily in science classes taught by a single instructor at a single, middle-class school. In other words, results may have been different had more classes participated in the study. Finally, had this study been conducted in a lower socioeconomic community with less access to science teaching, the results may or may not have been similar.

Despite these potential limitations, our study gives a deep understanding of teaching and learning science when used in conjunction with the elements and methodologies suggested by this research.

**Recommendations for Future Research**

The following suggestions for further research were identified during this study. Future researchers can collect names if they study the teaching practices of other teachers to have better access to the consistency of the data from different resources. Conducting a mixed-method study on a few teachers’ NGSS-based pedagogies might also provide more insight into science education by identifying further needs for teachers' preparation and professional development. According to Schram (2014), the mixed-methods approach allows for a more in-depth investigation of the various challenges that science teachers face.
Moreover, conducting this study in schools where minoritized students make up the majority of the school population could reveal important insights into the implementation of NGSS in such learning communities. Researchers could also compare newly adopted NGSS schools or districts with those who have experienced NGSS for a few years to identify the areas of improvement.

In summary, this study aimed to collect data to explore one teacher’s implementation of the NGSS that involved using engaging narratives with real-life examples, heterogeneous grouping with hands-on learning, and technology-based interactive activities in a safe and supportive learning environment. Collected data provided rich and detailed answers to the research questions coherent with the literature review and conceptual framework. This study revealed that students’ science identities were greatly influenced by the implementation of NGSS constructivist approaches that reinforced the valuing of science while constructing scientific knowledge. In addition, students improved their scientific critical thinking, problem-solving, and creativity skills through this process. These skills were boosted by collaborative communication working on NGSS based technology and hands-on activities following the engineering design process. Finally, this study showed that NGSS constructivist teaching pedagogies could lead to higher levels of learning and thinking that move beyond traditional pedagogies that focus on memorization of facts and concepts. In closing, I advocate science educators consider using the strategies outlined in this action research to complement their teaching to address students’ needs while preparing them for their future lives and careers.
Appendix A: Pre-and Post-Test Questions

Appendix B: NGSS Disciplinary Core Ideas

Appendix C: NGSS Performance Expectations

Appendix D: Science and Engineering Practices

Appendix E: NGSS Crosscutting Concepts
Appendix A: Sample Pre- and Post-Test Questions

Pre- and Post-Test Part 1    Day 1

Name:______________________
8th grade Physical Science    Date:____________
For Researchers Only - Pseudonym ______________

1. Define the following terms.

<table>
<thead>
<tr>
<th>Position</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement</td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td></td>
</tr>
<tr>
<td>Motion</td>
<td></td>
</tr>
<tr>
<td>Force</td>
<td></td>
</tr>
<tr>
<td>Interaction</td>
<td></td>
</tr>
<tr>
<td>Friction</td>
<td></td>
</tr>
<tr>
<td>Newton’s 1st Law of Motion</td>
<td></td>
</tr>
<tr>
<td>Inertia</td>
<td></td>
</tr>
<tr>
<td>Mass</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td></td>
</tr>
</tbody>
</table>
Pre- and Post-Test Part 2  Day 2

Name: ____________________
8th grade Physical Science  Date: ____________
For Researchers Only - Pseudonym ____________

3. Use the graph to the right to answer the questions below (Show your work).
   - Which runner won the race? ____________
   - Which runner stopped for a rest? ____________
   - How long was the stop? ____________

   - How long did Bob take to complete the race?
   - Calculate Albert’s average speed over the race.

4. Based on the model below, which statement explains which two objects have the greatest gravitational force between them?

   a) The objects with 10 g have greater gravitational force because they have less mass.
   b) The objects with 10 g have greater gravitational force because they have more distance between them.
   c) The objects with 25 g have greater gravitational force because they have greater mass.
   d) The objects with 25 g have greater gravitational force because they have less distance between them.
<table>
<thead>
<tr>
<th>Illustration</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Earth's gravitational force" /></td>
<td>A force that attracts (pulls) all objects to the center of the Earth</td>
</tr>
</tbody>
</table>
| ![Force and mass](image2.png) | The acceleration of an object depends on its mass and the force used to move it. F = MA  
F = force  
M = mass  
A = acceleration |
<p>| <img src="image3.png" alt="Racing cars" /> | The exact location of an object |
| <img src="image4.png" alt="Change in position" /> | Change in relative position of an object. |
| <img src="image5.png" alt="Distance and time" /> | Measures how fast an object is moving (speed) AND the direction in which it is moving. |
| <img src="image6.png" alt="Momentum concept" /> | The higher the velocity and mass, the more momentum an object has. Or how hard it will be to stop the object once it is in motion. |</p>
<table>
<thead>
<tr>
<th>Friction that acts between two objects that are in motion.</th>
</tr>
</thead>
<tbody>
<tr>
<td>For every action there is an equal and opposite reaction</td>
</tr>
<tr>
<td>The sum of all forces acting on an object</td>
</tr>
<tr>
<td>Scientist famous for developing the laws of motion. He is most famous for discovering gravity.</td>
</tr>
<tr>
<td>Not moving</td>
</tr>
<tr>
<td>The law states that when two objects collide in a closed system, the total momentum of the two objects before the collision is the same as the total momentum of the two objects after the collision.</td>
</tr>
</tbody>
</table>
Appendix B: NGSS Disciplinary Core Ideas

The scientific requirements to comprehend a particular science discipline are Disciplinary Core Ideas (Next Generation Science Standards Lead States, 2013).

- **PS2.A: Forces and Motion**

  For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton’s third law). (MS-PS2-1)

  The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. (MS-PS2-2).

- **PS2.B: Types of Interactions**

  Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object, a magnet, or a ball, respectively). (MS-PS2-5).

- **ETS1.A: Defining and Delimiting Engineering Problems**

  The more precisely a design task’s criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (MS-ETS1-1)

- **ETS1.B: Developing Possible Solutions**

  A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4)

  There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3)

  Models of all kinds are important for testing solutions. (MS-ETS1-4)

- **ETS1.C: Optimizing the Design Solution**

  Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the re-design process that is, some of those characteristics may be incorporated into the new design. (MS-ETS1-3)
The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (MS-ETS1-4)
Appendix C: NGSS Performance Expectations

- MS. Forces and Interactions
  MS-PS2-1. Apply Newton’s Third Law to design a solution to a problem involving the motion of two colliding objects.
  MS-PS2-2. Plan an investigation to provide evidence that the change in an object’s motion depends on the sum of the forces on the object and the mass of the object.
  MS-PS2-5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

- MS-ETS1 Engineering Design
  MS-ETS1-1. 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-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
  MS-ETS1-3. 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-ETS1-4. 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.
Appendix D: Science and Engineering Practices

- **Asking Questions and Defining Problems**
  
  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).

- **Planning and Carrying Out Investigations**
  
  Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim. (MS-PS2-2)

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

  Conduct an investigation and evaluate the experimental design to produce data to serve as the basis for evidence that can meet the goals of the investigation. (MS-PS2-5)

- **Constructing Explanations and Designing Solutions**
  
  Apply scientific ideas or principles to design an object, tool, process, or system. (MS-PS2-1)

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

- **Engaging in Argument from Evidence**
  
  Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. (MS-ETS1-2)
Appendix E: NGSS Crosscutting Concepts

The NGSS Crosscutting Concepts connect the many DCI to give a seamless learning experience for students. Such notions can connect each of the four DCI areas, including Physical Science, Life Science, Earth and Space Science, and Engineering and Technology paving the way for more profound levels of comprehension and application (KNILT, 2019).

The components of Crosscutting Concepts are as follows (Next Generation Science Standards Lead State, 2013).

- **Cause and Effect**
  
  Cause and effect relationships may be used to predict phenomena in natural or designed systems. (MS-PS2-5)

- **Systems and System Models**
  
  Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy and matter flow within systems. (MS-PS2-1).

- **Stability and Change**
  
  Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales. (MS-PS2-2)

- **Connections to Engineering, Technology, and Applications of Science**

  **Influence of Science, Engineering, and Technology on Society and the Natural World**
  
  The uses of technologies and any 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-PS2-1) (MS-ETS1-1)
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