Embedding Phenomena-Based Learning Practices Into a Middle School Science Curriculum

Allison Kubat

EMBEDDING PHENOMENA-BASED LEARNING PRACTICES INTO A MIDDLE

SCHOOL SCIENCE CURRICULUM

By

Allison Elizabeth Kubat

A capstone submitted in partial fulfillment of the requirements for the degree of
Master of Arts in Teaching

Hamline University

Saint Paul, Minnesota

December 2020

Capstone Project Facilitators: Jennifer L. Carlson and Julia Reimer
Content Expert: Rebecca Holscher
Peer Reviewers: Jenna Willi and Dillion Briesemeister

To my parents, thank you for all of the unwavering support and encouragement throughout my entire life. I am eternally appreciative of the time, energy, patience, and love you have graced me with in my life. I want to give an extra thank you to my mom who never stopped motivating me through this process and was never too tired to help work through an idea with me. You have shown me what strength and determination look like and I hope I can be at least half the role model you were to me to my future family. And finally, to my husband, Colby, thank you for encouraging me to achieve this goal and never letting me give up on myself. I could never have made it through this season of life if I did not know I always had you in my corner. I am forever grateful that I get to live this life with you.

TABLE OF CONTENTS

CHAPTER ONE

Introduction

Chapter Overview

All science discoveries start with an observation of a phenomena and are followed by a question that tries to explain the observation. A scientist then sets out to discover the answer to that question. Answers are found through reasoning, inquiry, and application. This was how dominant and recessive genes were discovered. Before Gregor Mendel began his work with pea plants, it was widely accepted that the traits of an offspring were a blend of parental traits. Mendel had a hard time accepting this because the studies carried out were not concrete and had holes. He sought to better understand how genes were passed on. If Mendel had not questioned the world around him, dominant and recessive genes would not have been discovered when they were. If he just accepted what he was told without questioning and exploring it further, genetic research would not be as far along as it is now. If great discoveries were made in this way, why is learning science in the classroom so passive? My question is: *How does embedding phenomena-based learning practices into middle school science curriculum help students become critical thinkers and develop a deeper understanding of the scientific content?*

In many classrooms today students sit and listen to a teacher drone on about a topic they have very little experience with. Often students implant those thoughts into their heads long enough so that they can regurgitate it back for a test. In a matter of a few days, maybe even minutes, the concept is forgotten. The student has not truly learned in this scenario. They were not using their science skills to make observations, their curiosity and communication skills to formulate a question, or applying their scientific knowledge to search for and possibly find an answer. This type of learning is teacher-led; facts are presented to students and the students take the teacher's word and accept the information as truth. What if roles were flipped and students were able to lead the discussions and discoveries? What if, instead, the teacher dropped science "breadcrumbs" and the students created their own path to discovery? In phenomena-based learning (PhBL) students are collaborative, discovering connections, designing models, and ultimately making sense of what they observe. When students are taught the reasoning process, they develop a deeper understanding of the scientific world around them.

Chapter One of this capstone project is to serve as an introduction. This chapter contains a personal journey of becoming a teacher, what was noticed in the classroom and the deficiencies seen by teachers, a possible solution to alleviate the deficiencies, and how this teaching style impacts students in their future science endeavors and how they answer questions about the world around them.

My Beginnings

I grew up as something called a 'FacBrat'. This meant my mother was a faculty member at the local boarding school. My mom was not only a faculty member, she was also a dean. I grew up on the campus and fully immersed in a school environment my entire life. Students were constantly in and out of our house either for extra help from my mom or just looking for a place that could fill in for the home they left behind. My neighborhood peers were also children of faculty members, and we ate a majority of our meals in the dining hall amongst teenagers. I lived and breathed school. As a child of a teacher I saw a side of school that not many are privy to seeing. I saw all the hard work that goes into lessons and how much planning is put in outside of the work day. I saw how quickly parents could manipulate a situation to run a story to their child's advantage. I saw how curricula had to be updated yearly to fit the latest trends research was showing as best teaching practices. I was able to see first hand just how hard being a teacher is. For these reasons and more I never wanted to be a teacher. I was dead set against it.

I thought there was no way I would become a teacher. Instead, I wanted to be a physical therapist. I thought this until I went to Ghana and volunteered at an orphanage. I went to Ghana for a community health awareness initiative and helped out at the orphanage before and after school. I planned to help with basic medical work and go into schools and teach about first aid and HIV/AIDS awareness. I did this for about a week. Then one day I was bringing kids to school and one of the teachers did not show up. I had to decide if I wanted to abandon these kids for a day and leave them teacherless or step into the role of a teacher and give it a try. I chose the latter and it was absolute chaos. The next day a similar thing happened and kept happening the following days. Eventually my time in Ghana changed drastically from my original plans. There, I fell in love with teaching and knew it was part of my life journey. The kids here had such a thirst for knowledge and they wanted to know anything that I could teach them. I began seeing that teaching is about the kids and the success you want them to have. My perspective on being a teacher changed radically. The students I was teaching in Ghana were so eager to learn and were questioning the world around them. All they were missing was a way to satiate their curiosity. They were missing tools on how to find the answers to their questions. What learning looked like there was memorizing the textbooks that had been donated to the school. They memorized not only the facts, but also the questions that are at the back of the chapter word for word. I realized two major things through this experience. I learned that having students memorizing facts from a textbook is not the ideal way to teach and also that teaching was the career that was calling my name. When I got back from Ghana I cancelled my applications to physical therapy schools and began searching for teaching licensing programs.

Teaching Experience

When I first began teaching I was so overwhelmed. My first teaching experience was a long term substitute role. During this time I was just trying to keep my head above water. I met almost daily with another teacher who taught the same content. I pretty much mimicked everything she did and had very little autonomy in how I was teaching. I knew my teaching should be more inquiry-based, as I had learned in graduate school, but I felt too overwhelmed and nervous to do anything different from what the other teacher was doing. Fast forward to the next year, where I found myself at a new school and I once again felt overwhelmed with new circumstances and curriculum. The teaching I was doing in the new setting had more inquiry-based lessons, but still the main pattern of teaching was lecture on a new concept, do a lab or activity that enhances understanding, then have students apply their learning.

I knew I needed to change how students were learning. I was lucky to have kids that wanted to be successful and were driven by good grades. They listened to what I said and thoughtfully questioned what I was saying. They applied what I taught them and they showed me they understood. When I saw these students the next year they talked about the fond memories they had in science, but indicated that they didn't remember the major concepts we covered. This was so disheartening to hear as a teacher since as a teacher you want to think you are having a major impact on the students' education. A teacher could ignore this information and continue with their current practices because they have good test scores or could be motivated by this to create a more impactful curriculum. I am choosing to see this as motivation to create content that gives my students a deeper understanding of the material.

Another thing I am seeing is that students ask great questions, but they do not have the tools to find answers. Often I find myself so excited that my students are interested in a topic that I just give them an answer instead of leading my students to the answer. It is a disservice to students to give them the answers. When most of my students ask a question and the answer is not obvious or instantaneous, they quit pursuing the answer. I see them give up when there is a struggle. This is frustrating to me. I know with a little brain power they could get to the bottom of what they wanted to know. I just want them to apply the scientific concepts they already know to new situations. This would lead them to the answer or very close to the answer. Each time this happens I am reminded that they have not been given the skills to investigate on their own. The lack of resilience and tools students have is one of the reasons why student-led lessons can be challenging.

What would happen if we changed how we taught science? What if instead of giving students answers we give them the questions and the steps to find the answers?

Would students be more self sufficient and able to critically think about the world around them? What would happen if I more consciously embedded PhBL practices into middle school science curriculum?

Summary

Through my years of teaching I have seen students ask wonderful, thought-provoking questions, but not know how to solve them on their own. They typically turned to their teacher, who was often overeager to provide an answer for them. Instead, teachers should be setting up a classroom that not only promotes thought-provoking questions, but also a place where students are encouraged to think critically about their question and the teacher assists them in finding their answers for themselves. The question I am asking is: *How does embedding phenomena-based learning practices into middle school science curriculums help students become critical thinkers and develop a deeper understanding of the scientific content?* The final product of the capstone project is a curriculum for use in the middle school science classroom. The curriculum follows the new Minnesota 7th grade science standards and embeds phenomenal science into the student work through the year. The phenomena-based lessons expose students to what a scientist does and get them thinking like a scientist. The lessons elicit this thinking by presenting students with phenomena throughout the year and providing tools for them to access their science background to devise a solution to the circumstances. Using phenomena as a way to teach and learn science starts at the beginning of the school year and is used throughout the remainder of the year. The introduction of each new standard starts with phenomena and students use their skills to explain what is happening. The content-specific lessons in the curriculum were created by using the Minnesota state standards. The curriculum can be applied to any 7th grade Minnesota science classroom, but is also general phenomena-based lessons that can be used in any biology-based science classroom.

Chapter Two of this capstone project is a literature review of phenomena- based science and best practices in the secondary classroom. It looks into the history of science education, how inquiry-based science has improved science skills, and how phenomena-based teaching is currently being used in the classroom and how it can be implemented. Chapter Two explores how PhBL develops a deeper understanding of the science concepts being demonstrated. Another major theme that is investigated during this chapter is how this type of learning will influence students in the future. I will delve into how having these critical thinking skills not only improves their learning in science courses, but also will influence students as global citizens.

Chapter Three of the capstone project is a project description. It begins with an overview of the school dynamics and the personality of the student population. It gives an overview of how the curriculum was developed and the methodology used to design and create it. The chapter also addresses the outline of the curriculum and how it has been adapted to fit the referenced student population.

Chapter Four is a reflection of the capstone project. The chapter reflects on the literature review and what was most useful to the development of the project. This chapter highlights key understandings found when writing the curriculum and potential limitations of the project. Chapter Four also discusses how the project can be adapted for other schools and grade levels. Finally, it also explains why this project is a benefit to science education.

CHAPTER TWO

Literature Review

Chapter Overview

This literature review focuses on research surrounding the question: *How does embedding phenomena-based learning practices into middle school science curriculums help students become critical thinkers and develop a deeper understanding of the scientific content?* The research covers topics of the history of science education, Next Generation Science Standards (NGSS), inquiry-based learning, PhBL, and how students learn best. The section focusing on the history of science education looks into how the teaching of science has changed in the United States since it was first formally introduced in 1892. The NGSS section looks at the background of the science standards implemented in 2013 and the challenges teachers face when designing lessons surrounding the standards. The literature review also has a significant focus on inquiry-based learning. This section explores the different types of inquiry: the 5E model, teacher and student roles in inquiry learning, the strengths and advantages of this learning style, and the challenges of inquiry-based learning. There is also a review of PhBL and the background of this model, how best to implement this learning model, advantages for students and teaching using this type of inquiry, and the challenges students and teachers might encounter. Finally, this chapter investigates how students learn best and how these techniques can be applied to science education.

Changes in Science Education

In the United States, science education has changed significantly since it was formally introduced into the education system. This section examines how science education has changed and developed since it was first implemented. It will explore the challenges science education has faced and the new methodology that developed to address the issues. This section will also highlight the successes science education has seen and what made them successful.

In the United States, science is not only a staple in today's education, but also a valued core subject. This was not always the case in the United States. Prior to the mid-1800s, science education existed, but in an unconstructed manner. This continued into the late 19th century. In response to scientific and technological advances associated with the industrial revolution and an increase in student population, science education became a part of student course work in 1892 (Bybee, 2010). Harvard University put together a list of physics experiments that became the first set of national standards for science (Belcher, 2015). These standards became the foundation of science education for the remainder of the century.

During the early 1900s through the years of World War I, schools began to look at curriculum from a cost-effective standpoint. Science education, along with other disciplines, became a set of facts to learn rather than experiences (Bybee, 2010). By eliminating experiences, science education became sterile and students no longer engaged in the processing of science. But science was messy and laboratories were often chaotic both intellectually and physically. Keeping this in mind, John Dewey (1910), a leader in educational reform, wanted to create something that made science more of an inquiry process rather than a rigid and fact-based course of study. This led to the creation of the scientific method, with a step-by-step approach to answering scientific questions (Bybee). Dewey hoped to create something less structured, but in an ironic twist created something that was limiting and simply another structure to memorize. This method has been scrutinized over the last 100 years and yet it is still found in most scientific textbooks.

After the Cold War between the United States and the Soviet Union, science curriculum was vocabulary-heavy and textbooks lacked graphs and data (Belcher, 2015). Over the next couple of years it became evident that science needed a facelift. Jerrold Zacharias, a physicist at Massachusetts Institute of Technology, saw that there was a need for students to understand that evidence drives science knowledge (Mazuzan, 1994). He envisioned laboratory activities juxtaposed with other materials that would develop a deeper student understanding. Zacharias wanted students acting like scientists by using laboratory materials to find evidence and construct conclusions based on evidence, an approach similar to the inquiry-based approach found in many classrooms today (Belcher).

In the 1960s and 1970s, Robert Karplus, a theoretical physicist at the University of California, Berkeley and head of the Science Curriculum Improvement Study, thought science curriculum should be a learning cycle that included exploration, invention, and discovery (Bybee, 2010). This cycle is still a driving force in science education today. Trends that have appeared in science education have branched off the cycle that Karplus created. In the 1980s, a teaching practice called Modeling Instruction was introduced.

This type of teaching was much more student-centered and inquiry-based. This learning style took laboratory skills and combined them with scientific inquiry. The use of models was meant to explain physical phenomena rather than solve problems (Belcher, 2015). Best practices for teaching science since the creation of Modeling Instruction have been centered around a student-led and inquiry-based learning.

In recent years, *A Framework for K-12 Science Education* (2012) was written and the NGSS (2013) were created from the framework which catalyzed PhBL. This teaching practice has recently sprung to the forefront of science education. PhBL is presenting students with scientific mystery and having them use their prior science knowledge to try to explain it. The teacher's role in this type of learning is to present the phenomena and guide students to use their own background knowledge and reasoning skills to reach a conclusion. Teaching this way allows students to think critically and more like a scientist, and through this process of analysis develop a deeper understanding of the scientific content.

Next Generation Science Standards

Many states have adopted common standards in K-12 math and language arts and have looked to continue this trend for science. A report called *The Opportunity Equation* was created by The Carnegie Corporation of New York and Institution for Advanced Study, and called for a set of common standards (National Research Council of the National Academies [NRCNA], 2012) This initiative was the beginning of a two-fold process: the NRC developed *A Framework for K-12 Science Education* and from that the Next Generation Science Standards (NGSS) would be created (NRCNA). This building of the framework used numerous studies and research and built upon what was already in place. The NRC determined that there were three main reasons science education in the US seemed to fail:

1. A lack of systematic organization throughout K-12 school years.
2. Education focused on facts and breadth over depth.
3. Students did not have the opportunity to engage in science authentically.

After considering the failings of the current methods and the previous research carried out with regards to the effectiveness of science education, the goals of the framework were put in place.

> The overarching goal of [the] framework for K-12 science education is to ensure that by the end of 12th grade, *all* students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of science and technological information related to their everyday lives; are able to continue to learn about science outside of school; and have skills to enter careers of their choice, including (but not limited to) careers in science, engineering and, technology. (NRCNA, 2012, p.1)

The framework was created keeping these goals in mind. *A Framework for K-12 Science Education* was rooted in the idea of keeping science education consistent throughout primary and secondary science education and building upon disciplinary core ideas and cross-cutting concepts throughout the years while actively engaging in science and engineering practices (NRCNA, 2012). The framework is divided into three dimensions and this was the basis of science education from K-12. These dimensions are outlined in Appendix A.

After *A Framework for K-12 Science Education* was developed, the next steps were to create the NGSS. The NGSS were a set of content standards for K-12 science developed by states to improve science education for all. The standards are a set of guidelines for which science skills students should know and be able to do by the end of each grade level. It was planned so that by the end of 12th grade, students would have a comprehensive science knowledge that ensured they were college and career ready (Lee et al., 2014). The NGSS (2013) believed educators should use these standards to create "learning experiences that stimulate students' interests in science and prepare them for college, careers, and citizenship" (para. 3).

Within the standards there are three dominant and equally important science dimensions. The three dimensions are cross-cutting concepts, science and engineering practices, and disciplinary core ideas. These dimensions are reflective of *A Framework of K-12 Science Education*. The dimensions are meant to work fluidly together and when one dimension is dominating, the other two are meant to support and build a cohesive understanding (NGSS, 2013). There are four main domains of science: physical science, life science, earth and space science, and engineering design. The Crosscutting Concepts domain has students explore the relationships between the four areas (NGSS). It is important for students to have a strong understanding of the scientific world around them and by exploring the connections between the core science domains students will have a better understanding of their world. The second dimension of the NGSS is Science and

Engineering Practices. This dimension has students behaving as scientists and students mimicking how scientists investigate the natural world around them and how engineers design (NGSS). This domain incorporates key scientific and engineering practices where students not only need scientific skills, but also knowledge specific to the practice that they apply to each standard (NGSS). The final dimension is Disciplinary Core Ideas and this focuses on the key ideas in science. The core ideas are introduced early on in a child's education and, as they progress through school, those ideas are built upon and go deeper in depth (NGSS). This emphasizes the idea of depth, not breadth, which was examined in the creation of *A Framework for K-12 Science Education*. The key ideas come from the four domains mentioned previously. These three dimensions are embedded into each of the NGSS.

The NGSS were released in 2013 and so far there have been 26 states that have applied to be lead states, which means they are strongly considering adopting the standards (NGSS, 2013). There are, however, some complications to adopting fully to the NGSS. Teaching the NGSS assumes the responsibility of ensuring that all students understand the rigorous and comprehensive standards (Lee et al., 2014). The NGSS are ambitious and call for teachers to develop lessons that are simultaneously thought-provoking, highly responsive to students, sense-making, appropriate for all students, and offer deep questioning (Mitchell et al., 2019). In an ideal situation, all science lessons would include these criteria. But this is not possible. To create lessons that are all this and more it would require ample time to reflect on students' previous work and learnings, collaborate with colleagues, and design the needed materials and supports (Mitchell et al.). Mitchell et al. found that even the most well-informed science teachers struggle to successfully implement all three dimensions into their lessons. Teachers are already overwhelmed with responsibilities and pinned into a daily structure that allows for limited curriculum development. It is difficult for teachers to find time to plan when there is already so much on a teacher's plate. Creating a quality lesson that follows the ideals suggested in the NGSS on a regular, preferably daily, basis, simply is not realistic for most teachers, at least not initially. Also, the nine-month contract with limited professional development days makes it hard to imagine that a teacher or school would have enough time to manipulate the curriculum to meet the needs of NGSS (Mitchell et al.). On top of time teachers often need more physical space and an increase in funds, which are both incredibly difficult to come by in most districts (Mitchell et al.). Teachers are unaccustomed to teaching science in this new manner and aiming to reach new expectations has shown some complications, especially in schools that are low on resources (Lee et al.). Mitchell et al. suggest there is a large concern that if teachers even have the capacity to make such a shift in science teaching practices.

Having a strong working knowledge of *A Framework of K-12 Science Education* and NGSS will aid in the creation of the phenomena-based learning curriculum. The curriculum will have strong ties to the NGSS. It is imperative to understand why these standards have been created and how they can be used in the classroom. It is also important to research the challenges that come with the NGSS and what problems might come up during curriculum development and how to avoid it.

Inquiry-Based Learning

At its most basic foundation science is motivated by inquiry. It is the process of asking a question about the surrounding world and finding answers. As mentioned previously, science content in the classroom is not always delivered in a way students can engage in inquiry. The NRC (1996, p.214) has said that, “inquiry is a critical component of a science program at all grade levels and in every domain of science”. There is a large push to move science education in the direction of students asking more questions and seeking answers themselves and this method is, in fact, becoming crucial to today’s science instruction. The name of this type of method is known as inquiry-based learning. The pedagogy behind this method strays from the typical teacher-centered approach where the teacher delivers content, and instead is student-centered learning where students explore science concepts and the teacher is only meant to guide learning (Biological Sciences Curriculum Study [BSCS], 2009).

Students who practice inquiry in the classroom engage in many of the activities and thinking processes that scientists do. One of the strengths of this instruction method is that it encourages students to act as scientists, rather than simply students absorbing knowledge. Inquiry helps students develop their own understanding and knowledge about a topic (BSCS, 2009). Students also have high levels of motivation in a classroom setting that is grounded in inquiry lessons. Engagement increases students' inherent curiosity about the natural world around them. When curiosity is heightened, a student will be more likely to seek answers to their questions and actively participate in their learning (Patrick & Yoon, 2004). When discussing inquiry in the classroom there are several important areas to address. This section will explore the BSCS 5Es instructional model, a common lesson plan outline that many inquiry lessons follow, and the role of a teacher and the role of the students in a 5E inquiry-based lesson. Researching and understanding these areas will assist in the creation of the phenomena-based curriculum by providing an inquiry-based foundation.

There have been several inquiry-based curricula created in hopes to promote higher order thinking (Marshall & Horton, 2011). When researching and developing an inquiry-based lesson, a trusted resource has been the BSCS 5Es instructional model. This model was originally put together by Rodger Bybee and a team of colleagues over 25 years ago (Bybee, 2014). This model was an adaption of Karplus's learning cycle. When the team created this methodology there were four things strongly considered: the model would have been grounded in research, challenged students' current conceptions, provided perspective for teachers, and was understandable and usable for teachers. When the researchers asked themselves what perspective teachers should have had, five common words kept being brought up: engage, explore, explain, elaborate, and evaluate. These terms became the five 'E's of the 5E instructional model (Bybee).

Engage, explore, explain, elaborate, and evaluate are the foundation of the 5E instructional model that Bybee (2014) described and lessons are created from these steps. The first step of the model is engagement. This phase should capture the interest of the students. During this phase the teacher presents students with an event, question, or anything that sparks wonder. When a student asks a follow up question or is puzzled, they are engaged and it is time for the next step, exploration. During this step, the lesson should provide an experience that allows students to investigate. The role of the teacher during this phase is to initiate the activity, give appropriate background, and provide the right equipment. After this has been administered the teacher should step away and let the students guide their exploration. The next step in the 5E instructional model is explaining. Bybee suggests that at this point students use their science knowledge and personal experiences to describe what is happening. It is now up to the teacher to provide the scientific concepts, but briefly and explicitly. After this the teacher presents students with another, but similar, situation and students then take the scientific concepts and elaborate on them. Finally, the teacher evaluates the elaborations. Here the teacher determines what evidence will serve as understanding. Bybee (2014) wrote that during the evaluation phase it is important to incorporate students.

Currently, science education is driven by inquiry-based learning. The National Research Council (1996) says,

> Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (p.1)

Since the inquiry-based learning method has been suggested to be the ideal way to teach science it has developed over time. One of the sub-developments of inquiry is PhBL. PhBL uses phenomena related to the science concept to spark wonder and interest in students and uses this as the basis of a lesson. During the lesson students explore the phenomenon and initially develop their own explanations to describe the phenomenon. Later the teacher clarifies the reasoning and students extrapolate this information to a new situation.

Phenomena-Based Learning

A Framework for K-12 Science Education (2014) highlights that students of all backgrounds should be able to make sense of scientific phenomena. Before beginning to create a lesson plan and teach phenomena it is important to have a deep understanding of what PhBL is. Merriam-Webster (n.d.) defines phenomenon as, “a fact or event of scientific interest susceptible to scientific description and explanation; a rare or significant fact or event”. From a science educator’s perspective, PhBL presents students with an interesting phenomenon that is anchored to the learning outcome and follows up the phenomenon with contextualization and relevance (Metz, 2018). Students then use their scientific knowledge and background to explain the phenomenon at hand. Previously, science in both practice and education has been guided by a list of facts, which reinforced the notion that science is learned by knowing facts. Facts are nice to know, but they can be so far removed from the work of scientists and actual understanding of science. Teaching and learning science should be delivered in a way in which students behave like scientists and are able to explore concepts and make their own discoveries in their learning. This is exactly what PhBL brings to the table. Mitchell et al. (2019) found that phenomena-based teaching is also rooted in three-dimensional science teaching outlined in the NGSS.

When PhBL is implemented there is a shift in pedagogy and new classroom dynamics emerge. Instead of a teacher-centered lesson, students drive the work and design the explanations and experiments while teachers serve as guides to ensure students are on the right path (Bendici, 2019). The Exploratorium Teacher Institute suggests that teachers should participate in PhBL to help them understand phenomena-based teaching and how to make it accessible to their students (Mitchell et al., 2019). This active learning experience helps teachers understand what a student will go through in a phenomena-based lesson. When engaging in learning this way a student's interest is piqued, they experience wonder, and end up with a deeper understanding of the phenomenon (Mitchell et al.). Ideally after engaging in a phenomena-based activity teachers will have a better understanding of the methodology involved with PhBL, and what they need to create a lesson. They will also have a deeper appreciation of the methodology involved with PhBL and see the importance of it in their curriculum.

Creating phenomena-based lessons can be overwhelming and there are several suggested methods that aid in the creation of this type of inquiry. This can be daunting, but there is common overlap in the various methods. Hancock and Lee (2018) developed a process that paralleled other methodologies found during research. Their process for creating PhBL is outlined in three main, basic steps:

1. Choose a phenomenon that informs the development of the driving question(s) that will guide the unit.

2. Identify what students know about how and why that phenomenon - and other supporting phenomena- happen, and

3. Design instructions to help students make sense of and explain phenomena related to the driving question(s) (p.1).

When picking the phenomenon it is important to consider students' grade level, prior experiences, cultural relevance, and developmental level. The phenomenon also needs to be engaging and challenging for students, yet not overwhelming (Metz, 2018). Finding just the right phenomenon for a NGSS lesson can be challenging, but when these needs are met the success rate of seeing students with a deeper conceptual understanding is high.

Teachers also need to know what students know. Evaluating students' prior knowledge is an important step in PhBL for two reasons. This is incredibly useful information when creating a phenomena-based lesson because it allows the teacher to design something that will lead their particular set of students to the desired results. Hancock and Lee (2018) found it is important for students to recall previous knowledge on their own. This serves as the foundation for student discovery and allows them to critically evaluate the phenomenon.

The final step in PhBL outlined by Hancock and Lee (2018) is designing an effective lesson. At this point, the teacher will use the phenomenon to create an inquiry-based lesson that is suitable for their students. When creating a lesson the teacher needs to present the phenomenon and then let students explore and discuss with their peers what they think is happening. The teacher should let students lead this portion of the lesson and only serve as guideposts to make sure students are on track. Once students have had a chance to explore on their own the teacher steps in and provides context to the lesson. It is important that a teacher incorporates this into their lessons.

One of the backbones of PhBL and why it is so significant is that students are able to behave and experience science like a scientist. Collaboration is one of the standards of being a scientist. Without collaboration science would be much further behind where it is today. Putting students into groups of three or four members is ideal. Not only do students enjoy working with peers more than by themselves, they also remember more when they are able to work together because they listen more intently to each other than their teacher (Bobrowsky, 2018). PhBL not only allows students to collaborate, but this teaching method also enables them to behave like scientists in other ways too. Students are able to make discoveries and find connections, design and create models, and make sense of what they observe (Bendici, 2019) All things actual scientists do. Getting students to think and behave like scientists is one of the most important pillars of *A Framework for K-12 Science Education*.

From a teacher's perspective, PhBL sounds idyllic. There are, however, some challenges that arise. Marshall and Horton (2011) believe the teacher is the greatest factor in increasing student academic achievement. Well prepared and knowledgeable teachers tend to be some of the best teachers. Therefore it is incredibly important for teachers to be well equipped to deliver phenomena-based lessons.Teachers need to be ready to, "facilitate investigations and conversations that help students analyze instead of recall, to justify instead of define, and to formulate instead of list" (Marshall & Horton, 2011, p. 94). Like with the NGSS and inquiry-based teaching, finding time to create these lessons in an already packed teacher schedule is difficult. This is something a teacher will have to devote extra time to creating. When Hancock and Lee (2018) studied and implemented PhBL in their classroom they found when presenting students with the phenomena, that many of them were not actively trying to solve the phenomenon at hand and instead were waiting for the teacher to provide context. They also found that while students were engaged in the phenomenon, the underlying science content they were trying to get students to understand was not apparent (Hancock & Lee). When creating phenomena-based lessons, a teacher needs to take these issues into account and plan a lesson that will, hopefully, prevent these issues from arising.

Humans have a natural urge to make sense of their world. Phenomena-based learning allows students to fulfill this desire. This approach encourages students to observe natural phenomena and to use their scientific knowledge to explain the cause behind it. Presenting students with phenomena binds the scientific concepts and practices. The real learning is when students start to use their science skills and knowledge to figure out the how and why of the phenomenon. When this is achieved students are participating in real science. The goal of this capstone project is to create a curriculum that embeds phenomena into middle school science standards. This will help students become critical thinkers and develop a deeper understanding of the science content.

How Students Learn

The way students learn best has been researched and discussed for eons. In order to create a successful curriculum it is important to have a solid understanding of what experts believe is the best way for students to learn according to the research they have conducted. It is important for teachers to know what studies find are the ideal ways that students learn and it's equally important for them to implement this knowledge into their teaching strategies and plans. This section will look at the work of Carol Dweck and what it means to have a growth mindset and its importance in a science classroom. It will also explore the book, *Make It Stick: The Science of Successful Learning* and the ways Brown et al. (2014) outline for making learning long lasting. Finally this section will review Benedict Carey's book *How We Learn* and the techniques given to create longer lasting memories.

The thoughts students have about themselves and their ability to learn might have a large impact on the classroom and student success. In her book, Carol Dweck (2006), the author of *Mindset: The New Psychology of Success*, outlined two types of thinking: a fixed mindset and a growth mindset. A person with a fixed mindset believes that people are born with certain abilities and that there is a threshold of predetermined knowledge that cannot be surpassed. A person with a fixed mindset might say something like, "I cannot do this, it is too hard and I am not smart enough", whereas someone with a growth mindset might say, 'This is challenging, but with more practice I will be able to get this'. In a growth mindset a person does not recognize failure as an obstacle, but rather as proof of learning. In this mindset, effort is praised rather than speed and natural talents. In a growth mindset students are not afraid to make mistakes and they understand that errors are part of learning.

Failure is almost a guarantee when asking students to describe an unknown phenomena using only their prior knowledge. To account for this failure and to prevent students from getting discouraged it is imperative to set up a classroom that supports a growth mindset. Dweck (2006, p.197) suggested, “A great teacher believes in the growth of the intellect and talent, and they are fascinated with the process of learning”. In PhBL there will be failures but these failures are all a part of the learning process. It is important for a teacher who is using PhBL to cultivate a growth mindset classroom. Once students believe in a growth mindset they will be ready to learn more efficiently.

Patrick and Yoon (2004) studied four eighth grade students of different cultural backgrounds. These students had a teacher who frequently delivered inquiry-based instructions. The study lasted for six weeks and during this time Patrick and Yoon evaluated the motivation levels of these four students. While the students were highly motivated they found a couple of unexpected results. One of the unexpected results was how a student’s concern with how their peers perceived them played a role in motivation. When the students were worried about how their classmates viewed them if they were incorrect their motivation and engagement decreased. It was assumed that students did not want to participate as readily because of a fear of looking stupid. To avoid this happening in lessons it is important to cultivate a growth mindset classroom.

It is important to know how to best implement growth mindset strategies into a classroom. Using growth-focused language is one of the most impactful things a teacher can do in the classroom to promote a growth mindset in students (Dweck, 2006). Before the learning even starts the teacher needs to set up a growth mindset classroom by letting students know that the teacher believes the students are developing people and the teacher is interested in aiding in the students’ development. It is important to set up a positive learning environment where students know it is okay to fail and that their teacher supports them. The language in the classroom should also praise effort, not natural ability. It could be detrimental to tell a student how smart they are. Teachers should focus on applauding the work that went into learning something new and highlight the hard work they put in. Setting up a classroom this way promotes students to embrace failure as a path toward growth. Set students up to not be afraid of failure, and when this happens, learning can be extremely fruitful.

Brown et al. (2014) expressed that lecture and memorization have been found as a poor way to teach and learn. Rather, the authors suggested, the learning needed to have been active and in the moment. They also suggested that it was important to have students try to solve a problem before learning the solution. This was still true even if errors occurred. Learning like this prevented the knowledge from disappearing over time and strengthened neural pathways.

Brown et. al (2014) suggested there were many ways to make learning new concepts ‘stick’ and highlighted them throughout their work. Two concepts stood out: the first emphasized that prior knowledge was essential for new learning and the second was that constant recall of the material built stronger connections. Students needed prior knowledge to serve as the foundation of new knowledge. When students were exploring a new phenomenon they would have used their previously learned language to describe and try to solve what was happening. Brown et al. believed that the more you could explain the new situation with your prior knowledge, the more it would stick and students would create deeper connections that would allow for better recall later. This was important to keep in mind when developing a curriculum. Students who searched for their own explanation and rooted these conclusions to their prior knowledge were at an advantage and were able to master the concepts quicker.

Brown et al. (2014) also focused on how to make learning last longer by strengthening pathways in our brain. The more students applied their new knowledge the better they understood the concept. Each time the brain recalled information the neural pathway got deeper and stronger and the speed of recollection was quicker. Brown et al. encouraged teachers to give students ample opportunities to use their new knowledge. It was recommended that students do not use any notes when they have to recall new information. One of the tips given to teachers was that after a new concept is introduced, students should put away all their work and spend 5-10 minutes writing down everything they remember (Brown et al.). This was suggested as a crucial step in developing neural pathways. The knowledge was there and when students had to 'search' for it in their brain the pathways were formed. When students skipped this step and looked at their notes the pathway was disrupted and it did not form (Brown et al.). Both using prior knowledge and providing students opportunities to practice their knowledge helped students remember new information. These techniques should be considered and applied to the creation of science curriculum.

Summary

There is a lot of research that backs *A Framework for K-12 Science Education* and the NGSS and their effectiveness. The standards are complex and have several tiers of learning within one standard. Often it is difficult to properly and effectively implement the NGSS in the classroom due to lack of education, resources, and time. Inquiry-based lessons offer a way to include the three dimensions of the framework: cross-cutting concepts, science and engineering practices, and disciplinary core ideas, into the learning. Teaching science from the lens of inquiry-based learning will lead to an increased demonstration of understanding for the NGSS. Digging deeper into inquiry-based learning and providing a way for students to think even more critically about the natural world around them is PhBL.

The research done in this chapter is to help answer the question: *How does embedding phenomena-based learning practices into middle school science curriculum help students become critical thinkers and develop a deeper understanding of the scientific content?* This project curriculum uses phenomena as the foundation of lessons to help students better understand the 7th grade science standards in Minnesota. The project creates a curriculum using the science standards determined by the Minnesota Department of Education.

Chapter Three outlines the methods used to create the phenomena-based science unit. The unit closely examines the NGSS and uses phenomena to help students develop a deeper understanding of these standards. The methods also take into consideration the works of Carol Dweck and Brown et al. This helps in the creation of lessons.

CHAPTER THREE

Methodology

Chapter Overview

Over the years, schools and teachers have been approaching science in the classroom as a presentation of facts and vocabulary by the teacher with the students solely responsible for learning these facts and vocabulary, essentially memorizing. The learning is sterile and tremendously removed from the thinking and doing of actual scientists. In 2012 the National Research Council created *A Framework for Science Education K-12* and from that the NGSS (2013) were born. These standards operate on embedding three dimensions into each content area: Science and Engineering Practices, Cross-cutting Concepts, and Disciplinary Core Ideas. Often creating and implementing a lesson that truly follows NGSS practice is incredibly taxing on the teacher because of the time necessary to innovate and develop the new learning environment. PhBL is a teaching and learning practice that can be used in a classroom setting and accurately represents the dimensions of the NGSS.

Chapter Three provides an overview of the capstone project. This project consists of a curriculum using the NGSS and the Minnesota K-12 Science Standards, specifically the seventh grade standards. This chapter provides the background of the school setting for the project as well as the audience for the curriculum. This chapter also explores the curriculum design model used to develop the lessons in the project. Finally, this chapter outlines the content and format used in the curriculum plan.

The curriculum incorporates PhBL to elicit authentic science practices within the learning of science content. The goal is to use lessons grounded in the NGSS and the seventh grade standards in the Minnesota K-12 Science Standards to answer my research question: *How does embedding phenomena-based learning practices into middle school science curriculum help students become critical thinkers and develop a deeper understanding of the scientific content?* The created curriculum provides a year long plan of phenomena-based lessons for teachers to implement in their classroom.

The Setting and Students

The intended audience for my curriculum is a suburban school just outside of a major city in Minnesota. The district offers open enrollment and currently has 11,084 students within its nine schools. The school this project is written for is a sixth through eighth grade middle school that consists of about 500 students with seventh graders comprising about a third of that number. There is strong parent involvement within the community. Ninety-nine percent of parents give a positive rating when asked about the education their child is provided. Parents and families in this district place high values on education, faith, and community and this is evident in student attitude and parental support of their child and the school. The district also offers both Chinese and Spanish immersion programs that start in kindergarten. The middle school in this study is part of the immersion program and several of the students this study is intended for are enrolled in the immersion program. Science is not considered part of the immersion curriculum and these classes are taught fully in English.

The curriculum being designed is intended for seventh grade students in science. At this school there are three levels of science offered: general, honors, and accelerated. The curriculum being proposed is intended for use in the general science class which consists of students who are at grade level in science, but could also easily be adapted for honors students. Students have seven class meetings a day: one for each of the four core subjects, one period that alternates between art and physical education, one for a self selected enrichment class, and one that is split between lunch and advisory. Classes are 56 minutes in length so in a typical week, students have 280 minutes of science instruction. The lessons created take place during one class or multiple classes with length will be dependent upon each individual lesson.

Currently, Minnesota has not fully adopted the NGSS and has its own set of science standards, the K-12 Science Standards, but the Minnesota standards have strong ties with the NGSS. In fact, Minnesota was one of the states that participated in the creation of the NGSS (Minnesota Department of Education (MDE), 2020). In 2019, a proposed draft of new science standards was approved by the MDE. The standards in the draft are much more closely aligned with NGSS. Most of the wording used in the new Minnesota science standards matches the Middle School Life Science standards created in the NGSS. The new Minnesota science standards are set to be fully implemented by the 2023-2024 school year.

Curriculum Design Model

The development of this phenomenon-based science curriculum follows the *Understanding By Design* model created by Wiggins and McTighe (2011). This model follows a backward design approach where the teacher creates a lesson with the end goal in mind. The project uses the new approved draft of the seventh grade Minnesota K-12 Science Standards as a starting point and works from there by building lessons around the state standards. Wiggins and McTighe's *Understanding By Design* (2011) has the teacher following three steps to create their lessons: identify desired results, determine acceptable evidence, and plan learning experiences and instruction. The curriculum and lesson plans were developed by following these steps.

The first step in Wiggins and McTighe's *Understanding By Design* is "identifying desired results" (2011 p. 8). When identifying the desired results I asked myself, "What long-term transfer goals are targeted", "What knowledge and skills will students acquire", and "What established goals/standards are targeted" (Wiggins & McTighe, 2011 p.8). On a surface level students need to understand the seventh grade Minnesota K-12 Science Standards. The goal of this project, however, is deeper than students just understanding these science concepts. Students need to understand these concepts through lessons that get them thinking and acting like real scientists. This provokes stronger critical thinking skills while students are learning the science skill.

The second step Wiggins and McTighe (2011) define in their methodology is to "determine acceptable evidence". This step of creation determines what serves as evidence in the lesson that students have learned the desired concept. The evidence most likely will vary depending on the skill involved in learning and owning the particular concept. The best way to show mastery for each standard is identified in each unique lesson.

Planning the lesson and determining learning experiences is the third and final step of Wiggins and McTighe's *Understanding By Design*. This point in the planning process needed to be creative and design valuable phenomenon-based lessons that mimicked the BSCS 5E's model. This part will be different for each standard and will be the most variable in the curriculum design.

This project follows the three stages written by Wiggins and McTighe that have been outlined previously to create authentic and engaging science lessons. The created project determines the standards, identifies the evidence of understanding, and finally designs the path to get to the learning through a phenomena-based curriculum. Using this variation of backwards design helps to answer the question: *How does embedding phenomena-based learning practices into middle school science curriculum help students become critical thinkers and develop a deeper understanding of the scientific content?*

Curriculum Content and Format

This project creates a science curriculum for a seventh grade science classroom based off of the approved draft of the new K-12 Science Standards in Minnesota. The new standards are to be fully implemented by the 2023-2024 school year. The curriculum uses phenomena as an introduction to each science concept outlined by the standards. It then mimics the BSCS 5Es created by Rodger Bybee and allows students to explore the phenomena first hand, use their own words to explain the science behind the phenomena, elaborate on the science taking place, and potentially apply it to a new situation. The project follows the 5E model, but does not explicitly use the steps in this model; engage, explore, explain, elaborate, and evaluate. This format helps assess the central question:

How does embedding phenomena-based learning practices into middle school science curriculum help students become critical thinkers and develop a deeper understanding of the scientific content? The teacher will assess the success of this curriculum through reflection and informal student evaluations.

The phenomena-based curriculum addresses the following seventh grade standards created by the state of Minnesota in the K-12 Science Standards (Minnesota Department of Education (MDE, 2020). The standards have been organized into four major science disciplines and this is reflected below:

Unit Name	Standard	Standard Descriptions
LS: From Molecules to Organisms: Structure and Processes	7L.1.2.1.1	Conduct an investigation to provide evidence that living things are made of cells; either one cell or many different numbers and types of cells.
	7L.3.1.1.1	Develop and use a model to describe the function of a cell as a whole and describe the way cell parts contribute to the cell's function.
	7L.4.1.1.1	Support or refute an explanation by arguing from evidence for how the body is a system of interacting subsystems composed of groups of cells.
	7L.4.1.1.2	Support or refute an explanation by arguing from evidence and scientific reasoning for how animal behavior and plant structures affect the probability of successful reproduction.
	7L.3.2.1.2	Develop and use a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism.
LS: Heredity: Inheritance and Variations of Traits	7L.1.1.1.1	Ask questions about the processes and outcomes of various methods of communication between cells of multicellular organisms.
	7L.1.1.1.2	Ask questions that arise from careful observations of phenomena or models to clarify and or seek additional

		information about how changes in genes can affect organisms.
	7L.3.1.1.4	Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation.
LS: Evolution: Unity and Diversity	7L.2.1.1.2	Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth.
	7L.2.1.1.3	Analyze visual data to compare patterns of similarities in the embryological development across multiple species to identify relationships not evident in the fully formed anatomy.
	7L.2.2.1.1	Use an algorithm to explain how natural selection may lead to increases and decreases of specific traits in populations.
	7L.3.2.1.3	Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships.
	7L.3.2.1.4	Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment.
LS: Ecosystems, Interactions, Energy, and Dynamics	7L.2.1.1.1	Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.
	7L.3.1.1.3	Develop and use a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.
	7L.3.2.1.1	Construct an explanation based on evidence for how environmental and genetic factors influence the growth of organisms and/or populations.
	7L.4.1.2.1	Construct an argument supported by empirical evidence that changes in physical or biological components of an

		ecosystem affect populations.
	7L.4.1.2.2	Evaluate competing design solutions for maintaining biodiversity or ecosystem services.
	7L.4.2.2.1	Gather multiple sources of information and communicate how Minnesota American Indian Tribes and communities and other cultures use knowledge to predict or interpret patterns of interactions among organisms across multiple ecosystems.

This curriculum takes place during the entirety of a school year. There are a total of 14 standard-driven, phenomena-based lessons in the curriculum that can be used over the year. The length of the lessons varies depending on the content they address. There is one major lesson created for each of the four science disciplines that are outlined above. The lesson serves as an introduction to the core disciplines. These lessons begin with phenomena and end with the student understanding and able to apply the new science concept. Some lessons can be completed in one 56 minute period while others might take multiple days to finish. There are also smaller lessons created for the remaining standards not explored in the introductory lesson. These lessons take about half a class period to conduct. The lessons are similar, but vary to meet the needs of the phenomenon explored. The purpose of these phenomena exploration lessons is to serve as an introduction to the standards. These lessons have students explore, evaluate, and elaborate on the phenomenon at hand. Students further their understanding of the science concepts later on in the unit. The lessons later refer back to the introductory phenomenon, but do not necessarily reflect the BSCS 5E model. The introductory phenomenon lessons still have students thinking critically like scientists and will serve as the foundation for a deeper understanding of the science concept.

Summary

This chapter outlined the methods that were used to create the capstone project. It reviewed the setting of the school and the type of students for whom the curriculum is designed. It also described the atmosphere and structure of the school and its classes. This chapter provided the design plan that was followed when creating the curriculum. The curriculum development uses Wiggins and McTighe's Backwards Design (2011) to generate lessons. Finally, this chapter delved into the standards that the capstone project uses to create the phenomena-based curriculum.

Chapter Four is a reflection of the curriculum design model. It explores the challenges and successes faced in the curriculum writing process. Chapter Four also summarizes key learnings found when exploring the answer to: *How does embedding phenomena-based learning practices into middle school science curriculum help students become critical thinkers and develop a deeper understanding of the scientific content?*

CHAPTER FOUR

Conclusion

Chapter Overview

The goal of this capstone project was to answer the research question: *How does embedding phenomena-based learning practices into middle school science curriculum help students become critical thinkers and develop a deeper understanding of the scientific content?* I chose to focus on this question because I was becoming increasingly aware that students lacked the ability to analyze and assess a situation using their own knowledge. Instead of actively asking a question and searching for an answer, students were passive and approaching learning and gaining knowledge as merely accepting something given to them. I saw evidence of this almost daily and as their teacher I found this frustrating and worrisome. I knew that if students were not being resilient in the classroom and challenging their brains to come up with possible solutions to unknown answers they would potentially be lacking the crucial skill of critical thinking as they matured and this could continue throughout their adult life. This worry is what inspired me to ask myself, "How do I get my students to become more independent and critical thinkers?" I had heard of the new science teaching style, phenomena-based learning, as a possible answer to my dilemma and wanted to explore this as a solution in my classroom.

For this project I created a curriculum that will be implemented throughout the school year. The curriculum is largely guided by the new Minnesota Science Standards that will be fully implemented in the 2023-2024 school year. This curriculum focuses on each standard and offers a phenomena-based lesson to use as an introduction to each standard. The new Minnesota science standards have four core discipline areas. There is also one lesson for each of the core areas that are guided by the 5Es model: Engage, Explore, Explain, Elaborate, and Evaluate. For each of the lessons the teacher will reflect and evaluate the student's progress towards critical thinking.

This chapter reflects on the curriculum design process for this capstone project. The first part of this chapter synthesizes my research and how it guided my project creation. Next it focuses on my key understandings from this project and expands on the successes and hardships found when writing the curriculum. This section followed by limitations and implications of this project. Finally the project discusses the benefits my project can have for future classrooms, students, and educators.

Research Synthesis

When beginning my research for this capstone I was drawn to the history of science education and the circumstances that led science to inquiry-based learning. The hallmark of science standards are the NGSS. Many states have either already adopted the NGSS or have created their own variation of the NGSS, but all have strong roots embedded in them. I think it is important to have a solid understanding of these standards and the intention behind them. The NGSS are three dimensional and many teachers focus solely on the disciplinary core idea and neglect the other two areas: cross-cutting concepts and science and engineering practices. My research showed the importance of using all three areas in lessons (NGSS, 2013; NRCNA, 2012). Understanding the intention and the interconnectedness of the three dimensions helped me as a teacher understand why the NGSS have been deemed a hallmark of science curriculum.

PhBL is a branch of inquiry-based learning which was born out of the way to incorporate and teach the three dimensions of the NGSS. My question is: *How does embedding phenomena-based learning practices into middle school science curriculum help students become critical thinkers and develop a deeper understanding of the scientific content.* My main focus for this capstone was PhBL research, but to understand why PhBL was promoted and recommended as a way to teach science I had to learn how science education got to this point. In the literature review the research subsections started very generally and then each following section built on previous sections and ultimately narrowed down to PhBL. It was easy to find studies that promoted a phenomena-based classroom and implementation strategies (Bybee, 2014; Hancock & Lee, 2018; Metz, 2018). What proved more difficult was finding research that supplied evidence of phenomena-based learning as an effective teaching method. PhBL is a newer methodology and a branch of inquiry-based learning. In my research I found a lot of potential benefits of using this methodology, but the research lacked hard evidence of its successes. Due to the lack of research methodology it was difficult to create an assessment portion of my project. In lieu of a traditional assessment the assessment for this project is based on teacher observations. As the year progresses the teacher will evaluate students' critical thinking skills.

Key Understandings

There are two major understandings I came away with from this project: (1) there is not one lesson structure that fits all situations when it comes to creating phenomena based lessons; and (2) the creation of the curriculum was more challenging than originally anticipated. In addressing the issue of lesson structure it is important to acknowledge that presenting students with phenomena can be done in a myriad of ways. In the created curriculum alone, phenomena are presented through many different modalities including analyzing lab results, watching videos, discerningly viewing images, and creating and interpreting graphs. Since presenting students with phenomena varied so much the lessons created also varied. Originally I wanted all the lessons in the curriculum to fit into a neat template. The reason for this was threefold: (1) it would give the teacher a structure to use so they could more easily create additional lessons; (2) after doing a lesson or two the teacher would know what to expect in the future and from their students and they could adjust to their classroom needs; and (3) students would know what to expect when presented with phenomena and this structure would quell anxiety and questions around trying to do a new task and lend for more critical thinking. While creating the curriculum, however, I struggled with creating a lesson template that worked for all the standards and associated phenomena. I dropped the idea of having a singular lesson template and instead created lessons that had a common theme that runs throughout the curriculum. There is a handout in the curriculum called "Phenomena Handout" that is used in a majority of the lessons. When this handout is not used explicitly, the terminology and language from the handout are embedded into the lessons. The intention of keeping this common theme is a solution to the original constraints contained in having one lesson template.

My second key understanding, grappling with the issue of the creation of the curriculum being more challenging than originally anticipated, stems from the reality that while I was writing the curriculum I was also teaching full time. This is an ongoing reality that teachers face. I was creating lessons for my project, but also for my job while also ensuring that I was fulfilling the needs of my immediate classroom of students. Creating my curriculum was much harder than I anticipated, primarily due to a lack of time available to do it well. When I was writing my lessons I was trying to model the lesson recommendations given by the NGSS and I ran into the problem that I saw constantly coming up in my research, first hand. As I reflect upon my struggle to find the time to create the multi-dimensional lessons I realized this was exactly one of the challenges I found in my research about implementing the NGSS. My research indicated that one of the reasons educators found it difficult to create lessons that incorporated the three dimensions of the NGSS (Disciplinary Core Ideas, Cross-Cutting Concepts, Science and Engineering) was a lack of lesson designing time (Mitchell et al., 2019). This was a challenge I faced before I started my capstone paper and the included lessons, and at a significant level, my initial reason for being interested in building a curriculum. When I first started my teaching career I knew about the push to design lessons that not only taught the students the core subject but also included cross-cutting concepts and science and engineering practices which ideally taught science like actual scientists learn and discover. In my years leading up to this project I tried to incorporate as many inquiry-based lessons as I could, but ultimately found it difficult to find the time I needed to make a truly successful inquiry-based lesson. My goal in selecting this project was to create a curriculum that I and other middle school science teachers could use in the future. This would help alleviate the time constraints concerns that are associated with inquiry-based lessons. While I knew about the concern for planning time, I did not think about the time strain I would face creating my curriculum in addition to teaching full time.

Limitations

While there are many potential benefits to using PhBL in the science classroom, there are also some limitations and disadvantages to it. There were three major limitations that stood out to me as I was researching and creating the curriculum. Those limitations were a lack of specific learning goals, the limited implementation range, and the need for a strong facilitator.

Most of the phenomena used in this curriculum are not an exact fit for each standard addressed. Phenomena are meant to be used as a starting point to get students to observe and wonder about the natural world. It is meant to prime background knowledge and promote critical thinking skills. Teachers are then supposed to use the phenomenon as a pivot point to the specific learning target. This is one limitation: if there is a specific learning goal in mind that the teachers want students to achieve then using just phenomena is not the best approach. One of the unique and crucial aspects to the success of PhBL is that there are not any imposed learning targets because the goals are created during the learning process. The goal of this project is to get students to become more critical thinkers and the curriculum is using PhBL as a way to achieve this goal. This is partially also the reason why there are only four fully written lessons in this curriculum. The majority of the included lessons have associated phenomena that can be used as an introduction to a standard. The teacher then creates the remainder of the lesson based off of student needs. As a result, if having students understand a desired learning is what a teacher is looking for this curriculum does not necessarily achieve that result.

Presenting students with phenomena and asking them to explain what is causing the phenomena using only their prior knowledge and intuition can lead to a wide array of responses. Students' final and correct understanding of what is happening is dictated by the teacher. Without a facilitator, learners will struggle with learning the skills and knowledge required to explain the phenomena at hand. This is why it is important to have a teacher who has a strong understanding of each phenomenon. If the teacher has a weak understanding, chances are they will have a hard time leading students to a correct explanation of the phenomenon, and instead, the students can easily come away with misconceptions around the subject. The curriculum I developed has a PhBL for each standard written for Minnesota 7th grade science, but a majority of these lessons only include the phenomenon and a way to present it to students. There are only four fully written out lessons in the curriculum that start with phenomenon and end with an assessment of the learning target. Most of the lessons only have the initial phenomenon portion of a major lesson therefore the teachers using this curriculum will need to develop the remainder of the plans to get students to the final learning goal.

The last limitation of this curriculum is that it is written for a Minnesota 7th grade classroom. As mentioned before, the lessons were created as an introduction to each of the standards in the new Minnesota 7th grade curriculum that will be fully implemented in the 2023-2024 school year. This curriculum may not be useful to other states and grade levels. Classrooms outside of Minnesota and in a different grade than 7th may, however, still be able to use this curriculum. The standards have strong ties to the NGSS and much of the wording is the same or just slightly altered. This means a school outside of Minnesota that uses NGSS will be able to easily apply this curriculum with only the possibility of minor adaptations. An advantage to this curriculum that transcends the grade level restriction, is that they are mainly grounded in the field of biology. Any classroom that is rooted in biology could easily manipulate these lessons to match their student grade level. While this curriculum is created for a Minnesota 7th grade science classroom it can be adjusted to fit another classroom that follows NGSS or is based in biology.

Potential Benefits

My hope is that my curriculum will be used in a way that promotes students to become more critical thinkers. The curriculum is built to encourage students to pull from their prior knowledge and use this to analyze and explain phenomena related to the learning standard. This will help hone students' critical thinking skills, and it will allow students develop a deeper understanding of the concept.

I also believe my curriculum can be manipulated and work for other classrooms that are not science based. I hope to share my strategies with other departments because I believe encouraging students to pull prior knowledge to explain a current situation is incredibly important. The language in the Phenomena Handout that is referred to frequently through my project can be used in many situations. I can see using phenomena in a social studies or math classroom and having tremendous success. Teachers could start with a complex math problem or a moment in history and have students try to solve or explain what might be the cause behind the moment using purely their background knowledge. This will hopefully lead to a richer understanding of the topic in these areas and simultaneously encourage critical thinking skills.

Conclusion

This chapter summarizes the research and curriculum writing process that answers the research question: *How does embedding phenomena-based learning practices into middle school science curriculum help students become critical thinkers and develop a deeper understanding of the scientific content?* In this chapter I addressed what I learned through the research and curriculum writing process. I also summarized the successes and struggles I faced while writing the curriculum and how this connected to what I found in my research. This chapter also addresses some of the limitations and implications of my project. Finally, the chapter reflected on the benefits of my curriculum and the future triumphs it can have.

I enjoyed the capstone research and writing process and have already been able to take what I learned and apply it to my classroom. I was able to grow immensely as an educator and as a student. I feel I have a clearer understanding of how to process and breakdown the NGSS and successfully apply them effectively in a classroom. I also feel that I am able to more easily and confidently use phenomena in my classroom. I was also reminded of the importance of Wiggin and McTighe’s backward design model when creating meaningful lessons. I hope to share my curriculum with many other science teachers and help encourage other educators, both in the field of science and those in other subject areas, to use PhBL practices in their classrooms.

REFERENCES

Belcher, N. T. (2015). Modeling instructions in physical science: Effect on student achievement in physical science and mathematics. *University of South Carolina,*

Bendici, R. (2019). NGSS science promotes phenomena-based learning. Retrieved from https://districtadministration.com/ngss-science-promotes-phenomena-based/#:~:text=Phenomena%2Dbased%20science%20encourages%20students,with%20partners%20and%20design%20models.

Bobrowsky, M. (2018). Q: How can I make science fun and have students learn more by using phenomenon-based learning?. *Science & Children, 56*(2), 70-73. doi:10.2505/4/sc18_056_02_70

Brown, P. C., Roediger, H. A., & McDaniel, M. A. (2014). *Make it stick: The science of successful learning*. Cambridge, Massachusetts: Harvard University Press.

Biological Sciences Curriculum Study. (2009). What is inquiry? The biology teacher's handbook. National Science Teachers Association.

Bybee, R. W. (2010). *The teaching of science: 21st century perspective*. Arlington, Virginia: NSTA Press.

Bybee, R. W. (2014). The BSCS 5E instructional model: Personal reflections and contemporary implications. *Science & Children, 51*(8), 10-13. doi:10.2505/4/sc14_051_08_10

Dewey, J. (1995). Science as subject-matter and as method. *Science & Education,* 4(4), 391–398. https://doi.org/10.1007/BF00487760

Dweck, C. S. (2008). *Mindset: The new psychology of success*. New York, NY: Ballantine Books.

Hancock II, J. B., & Lee, M. (2018). A new take on "tried and true". *Science Teacher, 85*(3), 43-48. https://doi.org/10.2505/4/tst18_085_03_43

Lee, O., Miller, E., & Januszyk, R. (2014). Next generation science standards: All standards, all students. *Journal of Science Teacher Education, 25*(2), 223-233. https://doi.org/10.1007/s10972-014-9379-y

Marshall, J. C., & Horton, R. M. (2011). The relationship of teacher-facilitated, inquiry-based instruction to student higher-order thinking. *School Science & Mathematics, 111*(3), 93-101. Retrieved from https://ezproxy.hamline.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=eft&AN=508188322

Mazuzan, G. (1994). The National Science Foundation: A brief history. Retrieved from https://www.nsf.gov/about/history/nsf50/nsf8816.jsp

Merriam-Webster. (n.d.). Phenomenon. In *Merriam-Webster.com dictionary*. Retrieved August 3, 2020, from https://www.merriam-webster.com/dictionary/phenomenon

Metz, S. (2018). Phenomenal science. *The Science Teacher. National Science Teachers Association*, *85*(3), 6–6. https://doi.org/10.2505/4/tst18_085_03_6

Minnesota Department of Education. (2020). Science. Retrieved from https://education.mn.gov/MDE/dse/stds/sci/

Mitchell, H., Phillips, M., Stokes, L., & Research, I. (2019). Helping science teachers experience phenomena-based science learning and understand the NGSS. final report of the exploratorium teacher institute's NIH-SEPA project. *Inverness Research*. Retrieved from https://ezproxy.hamline.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=ED603599&site=ehost-live https://inverness-research.org/reports/2019-04_Rpt_ExploSEPA-FinalReport-April2019.pdf

National Research Council. (1996). *National science education standards*. Washington DC: National Academy Press. https://doi.org/10.17226/4962

National Research Council of the National Academies. (2012). *A framework for K-12 science education*. Washington, D.C.: The National Academies Press.

Next generation science standards. (2013). Retrieved from https://www.nextgenscience.org/

Patrick, H., & Yoon, C. (2004). Early adolescents' motivation during science investigation. *Journal of Educational Research, 97*(6), 319-328. https://doi.org/10.3200/joer.97.6.319-328

Wiggins, G. & McTighe, J. (2011). *The understanding by design guide to creating high-quality units.* Alexandria, VA: Association for Supervision and Curriculum Development (ASCD).

APPENDIX A

Next Generation Science Standards Framework

THE THREE DIMENSIONS OF THE FRAMEWORK

1 Scientific and Engineering Practices
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

2 Crosscutting Concepts
1. Patterns
2. Cause and effect: Mechanism and explanation
3. Scale, proportion, and quantity
4. Systems and system models
5. Energy and matter: Flows, cycles, and conservation
6. Structure and function
7. Stability and change

3 Disciplinary Core Ideas
Physical Sciences
PS1: Matter and its interactions
PS2: Motion and stability: Forces and interactions
PS3: Energy
PS4: Waves and their applications in technologies for information transfer

Life Sciences
LS1: From molecules to organisms: Structures and processes
LS2: Ecosystems: Interactions, energy, and dynamics
LS3: Heredity: Inheritance and variation of traits
LS4: Biological evolution: Unity and diversity

Earth and Space Sciences
ESS1: Earth's place in the universe
ESS2: Earth's systems
ESS3: Earth and human activity

Engineering, Technology, and Applications of Science
ETS1: Engineering design
ETS2: Links among engineering, technology, science, and society