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Implementing The Next Generation Science And Engine

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IMPLEMENTING THE NEXT GENERATION SCIENCE AND ENGINEERING PRACTICES INTO A MIDDLE SCHOOL CLASSROOM

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"No longer can we treat our students as sponges for the knowledge that we provide. No longer is it the responsibility of the teacher to provide the explanations, design the experiments, and draw the conclusions. Rather, students must have the opportunity to do some of this work themselves." (Schwarz at al., 2017, p. 31).

Chapter One

Chapter One Introduction

There is no doubt that education looks different today than it did fifty, thirty, or even ten years ago. In today's day and age, many students have smartphones in their pockets and endless information at their fingertips. That being said, this shift in technology and society brings about different educational and social needs for today's students. In my personal opinion, school today should be much less focused on route memorization, direct instruction and multiple choice tests. Instead there should be a focus on preparing all students to be lifelong critical thinkers with a skill set that will help them be successful in our changing world.

I am not alone in my thoughts on adapting education to better fit our modernized world. In fact, many education professionals have also recognized this need to shift in education, especially science education. This realization has led to the creation of the Next Generation Science Standards (NGSS). According to the NGSS (2021), this complex set of science standards aims to, "create a set of research-based, up-to-date K–12 science standards. These standards give local educators the flexibility to design classroom learning experiences that stimulate students' interests in science and prepares them for college, careers, and citizenship" (2021). The goals of the NGSS have also been thought of as “sense-making,” a word to describe students making sense of the world they live in (Schwarz et al., 2017).

Next Generation Science Standards (NGSS)

The first time I heard about the NGSS was in 2016 while taking an undergraduate science pedagogy course. They sounded enticing, even back then, when I really didn’t know what they entailed. Since graduating in 2017, and throughout the four years of teaching I’ve had since, I continued to hear and learn more about the NGSS, although I was never required to truly include them in my practices. As time went on, I began to think of the NGSS as the best of the best in science education. I thought of it as an end goal that maybe one day I would reach, once I had more time to delve into that world. To me, the strategies and philosophies that go along with these standards sounded truly amazing in writing, but almost unattainable in practice, especially when there were so many other standards we are required to teach and assess. While I was, and still am, a teacher with a strong desire to modernize science education, and I believed that these standards could be very useful in doing that, I also felt like I didn’t have the extra time and energy to research and implement the NGSS.

Minnesota NGSS Adoption

Things changed in 2019 when it was announced that the state of Minnesota would be adopting new science standards that very closely resemble the NGSS. As an 8th grade science teacher in Minnesota I welcomed this change with equal excitement and anxiety. Since the announcement, these new standards have been a frequent topic of conversation for my colleagues and I. For some of us, this new style of science education will push us out of our comfort zone, while for others it isn’t too far off from our own teaching style.

As we began to dig into Minnesota's new science standards I found myself wanting to learn everything I could about the NGSS and the best practices used to implement them. This led me to my capstone research question, *how can teachers best implement the Next Generation Science and Engineering Practices to facilitate engaging and effective science instruction in an 8th grade classroom?*

District Rollout

The roll out of the new standards in my district has been delayed due to the COVID-19 pandemic. We will officially begin implementing the new standards in certain grades starting next fall, the 2022-2023 school year. This delay buys us a little extra time to prepare to make this switch, which I am grateful for. The work and research that follows through this capstone project has been done in an effort to better prepare myself for the change in standards. The rest of chapter one includes a brief summary of the NGSS, a run-down of this project's purpose, and an overview of what is to come in this capstone project.

Framework for the Next Generation Science Standards

The framework of the Next Generation Science Standards are described as *three dimensional*, which refers to the three components of the standards: the Science and Engineering Practices (SEPs), Crosscutting Concepts (CCs), and Disciplinary Core Ideas (DCIs). These three elements can be thought of as a braided system in which there is a SEP, a CC and a DCI that corresponds to each learning objective (Schwarz et al., 2017). This braided system was designed to encourage students to think and act like scientists and engineers, and in doing so, take charge of their own learning. The NGSS (2013) were designed in an effort to better prepare students for a modern world in which they can think critically and problem solve (Next Generation Science Standards, 2021).

Purpose

The purpose of this capstone is to provide educators with information on how to most effectively implement the Next Generation Science Standards. More specifically I will be researching strategies that can be used in a classroom to effectively incorporate the NGSS's Science and Engineering Practices. This work has been driven, in part, by an effort to better prepare myself and my colleagues to adopt Minnesota's new science standards.

While I have recognized the importance of adhering to the standards, a more personal reason for doing this work is to increase students' engagement in science and better prepare them for our modern world. Personally, I am growing bored of step by step labs and boring lectures, and I see that in my students as well. As a society, we know that science today looks much different than twenty years ago, and it is the job of educators to prepare today's youth to work and thrive in today's world. I believe this shift in science education philosophy could be incredibly influential in changing the science experience for our students, but only if teachers have been properly educated in making this change. While I cannot say for certain what the outcomes of this teaching philosophy may be, I am hopeful that a lasting effect of this work will be increased engagement and higher interest towards science among middle school students.

Guiding Question

The work in this capstone aims to answer the following guiding question: *How can teachers best implement the Next Generation Science and Engineering Practices to* *facilitate engaging and effective science instruction in an 8th grade classroom?* Throughout this capstone I aim to briefly explain the philosophy of the Next Generation Science Standards and then take a deeper look at each of the Science and Engineering Practices (SEPs). These areas of research and study were thoughtfully designed to have a better understanding of how to implement the SEPs in a middle school classroom. Finally, after thorough description, the research will then shift towards best practices to implement the SEPs into a middle school classroom scenario. This research also reflects my personal path of research to better understand the NGSS.

Chapter One Summary

Minnesota's 2019 science standards are noticeably different from the current standards that most educators in the state are adhering to. This new set of standards closely resembles the Next Generation Science Standards. This change will greatly impact science teachers around the state, which is why I have chosen to conduct research and document best practices around these standards for my capstone. This shift is exciting, as it enforces a new way of teaching that hopefully benefits students in better preparing them for our modern world. That being said, it is also a shift in the way teachers operate, so it brings about anxiety as well. This capstone aims to help myself, my co-workers, and anyone else reading it to better understand the new standards.

In the chapters to come there will be a thorough literature review of the NGSS's science and engineering practices (SEPs). This literature review, chapter two of the capstone, will include tips and strategies for implementing the SEPs in a science classroom. The following chapter, chapter three, will be a description of the project that accompanies this capstone. Finally, chapter four, will include a reflection of the work conducted throughout the capstone and capstone project.

Chapter Two

Chapter Two Introduction

Chapter two is a literature review that aims to gain more insight into the Next Generation Science Standards (NGSS) and specifically look into the Science and Engineering Practices (SEPs). Specifically, this chapter serves to answer the following question: *How can teachers best implement the Next Generation Science and Engineering Practices to facilitate engaging and effective science instruction in an 8th grade classroom?*

Chapter two will begin with a brief overview on the development of the NGSS and the three dimensions that encompass them. The next section will be on the importance and implementation of the Science and Engineering Practices (SEPs) within the NGSS. This section will go into more detail on each of the eight practices and will include strategies to help support students when implementing the practices into the classroom. Finally, this chapter will wrap up by discussing how best to make the transition to these standards and effective practices for implementing them into a science classroom.

Development of the Next Generation Science Standards

Overview of the NGSS

The Next Generation Science Standards (NGSS) are a set of educational standards written for K-12 science education. These standards were developed in an effort to make sure all students were getting an education that would benefit them in our modern world (NRC, 2014). The NGSS aims to reinvent science education by taking advantage of the natural curiosity children have for the world. This set of standards is really a framework designed to guide students in proposing authentic questions about the world and designing investigations around those questions. Through adoption of these standards students are actually doing science, like a scientist does (Colson & Colson, 2016). This shift in science education also creates a shift in the role of the teacher. In the NGSS the teacher acts more like a guide for students compared to the more traditional role of content expert (Krajcik, 2015).

In 2010 the first draft of the NGSS was released. The committee that came together on this project, referred to as the *framework committee*, included a variety of scientists with expertise in science content, along with science educators and policy makers with expertise in science education (Next Generation Science Standards, 2021). This committee was first tasked to come up with an agreement on what science knowledge all students needed to learn in K-12 education. In doing this, they found that it was equally important that students learn science skills and themes as it was important they learn science content. After making that realization, the framework committee came to the conclusion that the standards needed to be broken down into three intertwining strands that they call dimensions. The three dimensions include: the Science and Engineering Practices (SEPs), the crosscutting concepts (CCs), and the disciplinary core ideas (DCIs) (Schwarz et al., 2017). The goal of the three dimensions is to guide students in thinking and practicing science like scientists do (NRC, 2014). The three dimensional standards emphasize science content, as well as scientific practices and themes of science, which is something science standards have never done before. The framework committee has referred to the three dimensional learning as being, "intertwined knowledge and practice" (Schwarz et al., 2017, p. 65).

Disciplinary Core Ideas

One of the three dimensions that encompass the NGSS are the disciplinary core ideas (DCIs). This is the area that most closely resembles traditional science standards, as they are a progression of science ideas and knowledge that all students should learn. The framework committee organized these standards by grade level bands and content. The three content areas include: earth and space science; life science; and physical science. The grade level bands are: K-2; 3-5; 6-8; and 9-12. For each content there are explicit science standards that increase in sophistication as you progress through the grade level bands (NRC, 2014).

The DCIs are meant to guide student learning by providing a general idea of what students should know. It is up to schools to determine how they want to break up these standards within the grade level bands. It is important to note that the DCIs should not be thought of as different from the SEPs and CCs (Schwarz et al., 2017). In the case of the 2019 Minnesota Science Standards, in middle school they chose to break up the content so that each grade (6-8) was focused on one specific disciplinary science. That is the one large difference between the 2019 MN standards and the NGSS. In the MN standards sixth grade covers Earth and Space Science, seventh grade covers life science, and eighth grade covers physical science (Next Generation Science Standards, 2013c).

Science and Engineering Practices

The second dimension in the NGSS is the Science and Engineering Practices. Commonly referred to as the SEP’s, these practices are unlike most traditional science standards. They are a set of skills that scientists and engineers use to learn more about phenomena and engineers use to solve problems (NRC, 2012). The practices include the following: *Asking Questions and Defining Problems; Developing and Using Models; Planning and Carrying Out Investigations; Analyzing and Interpreting Data; Using Mathematics and Computational Thinking; Constructing Explanations and Designing Solutions; Engaging in Argument from Evidence;* and O*btaining, Evaluating, and Communicating Information* (Next Generation Science Standards, 2021).

The framework committee determined there were two strong reasons to emphasize the SEPs in these standards. The first reason being the need to better define what “inquiry” looks like in a science classroom, and the second reason being the need to redefine the scientific method to better represent what happens in real world science (Schwarz et al., 2017).

In education the word inquiry gets used a lot, but it is somewhat ambiguous in meaning. In reality, the practice of inquiry involves a number of skills, and it is important that students experience and practice all of those skills. The framework committee found that elementary science classrooms tended to focus heavily on observing and investigating science phenomena, while secondary science education stressed more learning about established science theories and laws. A true practice of inquiry involves students at all grade levels to use skills related to both examples. The SEPs were developed to ensure that students at all grade levels are practicing and refining skills in all areas of inquiry (Schwarz et al., 2017).

The second reason the SEPs were formed was to better redefine the scientific method so that it reflects the work of scientists and engineers (Schwarz et al., 2017). Traditionally, the scientific method was taught as a rigid, uniform, step by step set of practices that a scientist uses to complete their work. Many students interpret this set of steps as a one-way path that is never repeated or altered in any way. The reality is that scientists actually conduct their work using the practices of the scientific method, but not in the way of the rigid, step by step path. Scientists use a variety of the practices in differing ways and differing orders dependent on their investigation. They are also constantly revising and repeating their investigations, which is another component missing from the traditional model of the scientific method (COGEFS, 1945). For this reason the framework also found the SEPs to be a necessary part of the NGSS (Schwarz et al., 2017).

Crosscutting Concepts

The final of the three dimensions in the NGSS are the crosscutting concepts (CCs). There are seven CCs and they include: *patterns; cause and effect; mechanisms and conservations; scale, proportion and quantity; systems and systems models; energy and matter: flows, cycles, and conservation; structure and function; stability and change* (Next Generation Science Standards, 2013a). As Ravit Golan Duncan and Veronica L. Cavera (2015) describes it, “The CCs provide a set of lenses that can be used to explore and explain phenomena.” (p. 19). They can also be thought of as common themes in science that provide a way to frame a scientific problem or phenomenon. The knowledge of common themes suggest to students that science phenomena can be learned about through different lenses, which each have their own value and perspective (Duncan & Cavera, 2015). The framework committee developed the CCs for two main reasons: firstly, so that students can have a deeper understanding of the DCIs and secondly to guide students in developing a strong scientific view of the world (NRC, 2012).

Disciplinary core ideas are the science concepts that students study. When students are faced with an unknown concept or phenomenon that they are studying, they need mental tools to help them think about that concept or phenomenon in a scientific way. In the NGSS, the familiarity with CCs are tools that students can use to help them better understand the concepts they are studying (Next Generation Science Standards, 2013a).

Summary

The Next Generation Science Standards were officially completed in 2013 (Next Generation Science Standards, 2021). In 2019, the state of Minnesota adopted new science standards that closely resemble the NGSS. These standards follow the same three dimensional approach to science education. This includes three dimensions, or strands, that students should be learning in their K-12 science experience. The three dimensions include: the disciplinary core ideas, the science and engineering practices, and the crosscutting concepts.

The DCIs most closely resemble traditional science standards. These are a set of disciplinary specific standards that identify which scientific concepts students should know. The SEPs are a framework of practices that closely resemble the skills scientists and engineers use each day. This framework of skills should be used by students to learn more about the science phenomenon in question. It will help students investigate a science concept and learn more about it using the skills that scientists and engineers do. Finally, the CCs are themes of science that commonly occur throughout different disciplines. These themes should be brought up organically throughout students' K-12 science education as a means to better understand different scientific concepts and connections between the disciplines.

The three dimensions of the NGSS were designed to revolutionize science education. The goal of the NGSS is to get students engaged in sense-making about the natural world around them, using skills that are similar to the way scientists and engineers learn about the world around them.

Science Phenomenon and the Next Generation Science Standards

Introduction

This section focuses on the NGSS's science and engineering practices. It will begin with an explanation of "phenomenon learning," which is a core element of all dimensions in the NGSS. After this section, the review will go into the importance of each of the eight SEPs and the best strategies to use when implementing these practices into a science classroom.

Phenomenon Based Learning

The overarching goal of the NGSS is for students to figure out how and why something in the world happens in the way that it does. The "something" that students are aiming to explain is the unit phenomenon (Schwarz et al., 2017). A classroom aligned with the NGSS typically focuses the learning around one or many phenomena that relates to the science content area or the DCI students are working on. The very first step in a unit following this NGSS is to present students with a scientific phenomenon or engineering problem. Next, students are prompted to use the science and engineering practices to learn more about the phenomenon (Krajcik, 2015).

The focus on phenomenon is central in this framework, as it aims to stimulate student curiosity and wonder, motivating students in their work on the science and engineering practices. One strategy with phenomenon based learning is to make students a part of the phenomenon choosing process. Have students take photos and videos of naturally occurring phenomena they might want to study, and then the teacher can select a phenomenon that heads in the direction of the DCI for that unit. This allows for more autonomy and authenticity in science education, as well as differentiating the learning so that all students are being challenged at their own level. Engagement with the phenomenon can be through physical interaction, video, photograph, online simulation, or anything that allows students to make observations (Deverel-Rico & Heredia, 2018).

Implementation of the Science and Engineering Practices

Introduction

This section will be a summarization of explanations and best practices for the implementation of the Next Generation Science and Engineering Practices (SEP). It is important to note that there are two different sets of practices: the science practices which represent the work of scientists and the engineering practices which represent the work of engineers. Only two of the eight practices have differing science and engineering practices.

As you will see, in the first SEP, *Asking Questions and Defining Problems,* the action of *Asking Questions* is a science practice and the action of *Defining Problems* is an engineering practice. In the sixth SEP, *Constructing Explanations and Designing Solutions*, the first action of *Constructing Explanations* is a science practice and *Designing Solutions* is an engineering practice (Next Generation Science Standards, 2021). Please note that as you read through chapter two, SEP one and SEP six will be mostly focused on the science practices and not the engineering practices.

Asking Questions and Defining Problems

Questioning plays an important role in the NGSS. This is where students define exactly what needs to be explained about a phenomenon. In the science practices, the questioning process should begin with a phenomenon the students are observing. After making observations, students are then prompted to ask questions about the phenomenon. In engineering practices the first step is to define the problem, differing from *asking questions*. In both practices the teacher's role in this process is to help students refine and clarify their questions or problems so that they go beyond simple yes/no questions or naming/categorizing questions. These questions are the driving force that will guide students through the unit (Schwarz et al., 2017).

In their book, Christina V. Schwars, Cynthia Passmore and Brian J. Reiser include examples of asking questions in chapter 5. In one example students are studying the phenomenon of odor traveling. In the asking questions step students may begin to wonder what else is in the air instead of oxygen. This would be an example of a question that leads to empirical evidence, but not explanatory evidence for the phenomenon. In this scenario the teacher’s role would be to help the students refine that question into something that can be explored through an investigation. An example of a refined question might be *how did the stuff in the air get there?* (Schwarz et al., 2017, p. 93).

There are different strategies to help facilitate this practice of asking questions. One recommendation is to produce what is called a Driving Question Board (DQB) (Schwarz et al., 2017, p. 93). This is an area in the classroom where students will collectively house all of their questions in a shared and public way. This is also a place for students to keep track of what questions have been answered and what they still need to know. Once this question board has been created, the teacher can select one or two questions at a time for students to really dive into and study. It is important that the teacher continues to circle back to each question on the DQB, as that is a way for students to feel their voice and questions are valued and important in the learning process (Schwarz et al., 2017).

The DQB also lends itself to helping students organize their questions. This could happen in small groups or in a large class setting, but it really is where students can organize their questions into categories or topics. Once the topics have been established the teacher, with or without the help of students is able to map out the unit, based on the questions (Schwarz et al., 2017).

Another strategy that professionals have deemed important for the SEP is scaffolding. Teachers should be modeling the skill of questioning to help students better understand this practice. This might look like a teacher stating some of their own questions about a phenomenon, it might be a teacher refining a student question to help move an investigation forward or revise a model, or it could be a teacher demonstrating how to ask testable questions (Schwarz et al., 2017).

Finally, it is important to circle back and revisit questions that have been asked. When coming back to the DQB teachers should be asking students whether or not they have come up with an answer to their question. This is a strategy to help students keep track of what they have learned and what else still needs to be covered.

Generating questions is the first step in the SEPs. This step is important because it helps to guide the learning and investigations of the unit to come. A DQB is a great way for teachers and students to organize and refine their questions.

Developing and Using Models

Regardless of if you are following the science practices or engineering practices, the next practice listed is *developing and using models.* A model in the NGSS is an example or representation of the phenomenon being studied (Next Generation Science Standards, 2021). Students should be designing and developing models on their own. In science, a model can be thought of in many ways. Sometimes it can be an illustration and sometimes it is more like a small-scale replication of the phenomenon. The practice of developing and using models is a key step in students making sense of the world (Oh & Oh, 2011).

While engaging in this practice students should be doing two things: thinking about their model, and then thinking with their model. When students are actively thinking about their model they are designing the model. They are choosing items or drawing pictures to best represent the phenomenon. They are building their models, evaluating their models, and revising their models. Once students are content with their model then they shift to thinking with their model. This means that students are actually using their models to learn about and come up with an explanation for their phenomenon (Schwarz et al., 2017).

When using this practice in a classroom it should come after students have asked questions about a phenomenon. Ideally those questions are recorded on some type of DQB. Some of those questions should be refined into questions that are testable with a model. Once a testable question has been established students are tasked with creating a model of the phenomenon that will test the question. Teachers should remember that the modeling process will take multiple days and it will involve multiple cycles of evaluations and revisions (Schwarz et al., 2017).

When students participate in this part of the practice it can lead to more sense-making of the phenomenon. It allows students to deeper understand the phenomenon and construct better explanations than using a pre-made model or memorizing facts. Developing and using models is an important step that will guide students through the rest of the SEPs (Schwarz et al., 2017).

Planning and Carrying Out Investigations

In this phase of the SEPs students are planning their own experiments in an effort to learn more about a phenomenon, or to test a theory or model. This step comes after students have developed questions about a phenomenon and either before, after, or during the modeling process. This practice is the same for both the science practices and the engineering practices (Next Generation Science Standards, 2013b).

Investigations in this practice are designed and driven based on the questions that students have come up with. This is different from traditional labs done in science classrooms. The one big thing to keep in mind while practicing this framework is that students are NOT following a cookie cutter lab. The idea in this practice is that students are designing their own investigations to make sense of a natural phenomenon. A cookbook lab, or a lab in which students are closely following a set of the directions, does not allow for students to really connect with the phenomenon and see how the investigation helps them figure out parts of the phenomenon. This philosophy of using practices to help students design their own investigations and conduct their own research was developed to best resemble how scientists actually do their work (Duschl & Bybee, 2014).

When approaching this practice the first step is making sure that students understand the purpose of their investigation. It should be clear what the goals of the data are for students. After that, students are tasked with designing their investigation with the goals in mind. Depending on the phenomenon, students may decide that a controlled experiment would be best. This is an experiment in which most of the variables are controlled and the investigator is carefully choosing what to manipulate. While controlled experiments do have their time and purpose, it is important to know that not all investigations have to be controlled experiments (Schwarz et al., 2017).

A second type of investigation involves the investigators making observations and looking for correlations within their observations. Both controlled investigations and observational investigations are used by scientists in various fields, and both types should be used in the science classroom (Schwarz et al., 2017).

Measurements, observations and data derived from these investigations are used by students to make sense of the phenomenon in question. It is important that students are recording their results in some type of graph or data table as they conduct their experiment. There are many different ways to record data and they are dependent on what type of investigation the student is conducting. From these data tables and the results of their experiments, students are learning more about the phenomenon in question and the benchmarks being targeted (NRC, 2012).

Analyzing and Interpreting Data

Oftentimes, after completing research or an investigation students believe they have completed their work once they have the data in hand. At this point, students have not yet analyzed and interpreted their data, which is the heart of where sense-making occurs. To analyze and interpret data students need to be connecting their data to the question they are trying to answer or the purpose of their experiment. This is a practice done collaboratively by most scientists, so it is also a practice that should be done collaboratively amongst students (Schwarz et al., 2017).

The first part of this practice is to analyze the data. When students are analyzing the data they are looking for relationships between different parts and assigning meaning to the collected data. To do this, students are encouraged to use tools that help them make better sense of the data. Some examples of visual tools would be things like tables, graphs, venn diagrams, and many other visual displays. While these visuals are helpful in analyzing data, they are not the final product for this step. They are a tool to help students better interpret their data (Schwarz et al., 2017).

Once visuals have been created and relationships have been established, students will then interpret the data, which means they are explaining the meaning of the relationships. This scientific practice contributes to the way in which people think about science concepts and better understand how the world works. This step is complex and will require scaffolding by the teacher. Opportunities for students to interpret data should be revisited frequently as the year progresses to allow students ample opportunities to practice (Schwarz et al., 2017).

Finally, this step is where students begin to understand the connection between their interpretation of their data and how that begins to explain their phenomenon. It is important that students have the opportunity to make meaningful connections between the data they have collected and the phenomenon they are studying. As students begin to see the interconnectedness between their work and science concepts they may have a higher motivation and engagement towards science in general (Schwarz et al., 2017).

Using Mathematics and Computational Thinking

In science, using mathematical and computational thinking allows scientists and engineers to organize and analyze data in different ways. This practice involves students using mathematical formulas, graphs or computer simulations to better understand data. As they do so, they not only gain more knowledge on the phenomenon they are studying, but they also can begin to see how mathematical representations are in essence connected to the world around them (Next Generation Science Standards, 2013b).

This practice fits nicely with several other SEPs. Specifically, the act of using mathematical thinking could be helpful in creating models as well as in analyzing and interpreting data. Because many of these SEPs compliment each other, it is important to note that they do not need to occur in any specific order, and not all practices need to be used while studying one specific phenomenon (Schwarz et al., 2017).

While talking about this practice it is important to clarify the difference between mathematics and computational thinking. When using mathematical thinking, students are looking for patterns or trends in data, and they aim to explain those using numbers. Once students have identified a pattern or they have gathered quantitative data, students then are tasked with describing that data or relationship using mathematical symbols and equations (Sneider et al., 2014).

The mathematical portion of this practice is focused mostly on number data, while the computational thinking portion focuses on processes. Using computational thinking involves using computer models and other simulations to explore, test and learn more about a phenomenon (Sneider et al., 2014). Oftentimes, this part of the practice is used when the topic being studied is too large, too complex or too random to explain using mathematics (Schwarz et al., 2017).

Students use this practice to better understand, better make predictions and better describe a phenomenon. Specifically, at the middle school level, students should start using digital modeling tools and also simple basic mathematical ideas to collect and interpret data. In this step students should be making connections between the science they are learning and mathematical thinking or computational thinking. They should also be able to use the information they gain in this practice as evidence to support their learnings (Schwarz et al., 2017).

When beginning to do this practice with students there are some things that are important to do. The first is to try and motivate students to think past the "what" that is happening during an experiment and to instead think about "how often" or "how intense" something happens. Secondly, the teacher should intentionally create a classroom community that requires students to use mathematics and computational thinking. Having high expectations with the students from the start will be very important in achieving success in this practice (Schwarz et al., 2017).

Constructing Explanations and Designing Solutions

The practice of constructing explanations (for science) involves coming up with a written or verbal explanation that describes how or why a phenomenon is occurring.

When students are writing explanations they are expected to use their own findings and evidence, as well as using information they learn from the teacher and other classmates. Basically, students have to answer a question about the phenomenon and also provide evidence as to why it is happening. In engineering, this practice looks a little different. The engineering practice is designing solutions and is all about designing a solution to the problem (NRC, 2012). The rest of this section will focus on the constructing explanations practice.

When implementing this practice into a classroom there are several strategies that might make things go more smoothly. The first strategy is about writing good questions that force students to explain the how and why of the phenomenon. There are two guidelines to follow when writing the questions. One, it is essential that the questions students are being asked to explain are appropriate. The teacher should be thoughtful in constructing the question students are explaining. The wording of the question should be specific enough that students are sure of what they are answering. If it is too vague, students will struggle understanding what they are answering. Secondly, the question should be written in a way that requires students to provide evidence to answer it. If the question can be answered by simply defining something, it is not a good question. If the question is asking students to identify differences between two things, it is not a good question. Students should be truly answering the why and how of the phenomenon (Schwarz et al., 2017).

Another good strategy that will help students with this practice is to develop a classroom culture that focuses on constructing explanations. This means that this practice doesn't just occur at one moment of time in the classroom. Students should be encouraged to think and talk about evidence whenever they are making sense of a phenomenon. Sentence starters are a good way to support students with this. Two example sentence starters might be: *How does this help us answer our overarching question?* or; *What other evidence should we consider as we construct our explanation?* (Schwarz et al., 2017, pp. 225).

Scaffolding student's writing is a final strategy that can help students through this practice. Depending on the age, the writing portion of constructing explanations can be very difficult. Scaffolds for this might be sentence starters, prompts, visuals or questions. Basically, they should hint at what students need to make a part of their explanation (Schwarz et al., 2017).

Engaging in Argument from Evidence

The practice of engaging in argument from evidence is meant to resemble the importance of scientists and engineers coming together to share and dispute their findings. Historically, many science classrooms present science concepts as a set of facts, developed long ago, and this leads to students simply memorizing those facts. In the NGSS, the practice of engaging in argument from evidence allows students to participate in conversations that revise and edit old ideas and result in new ideas. This can change the way students think about science. Instead of believing that science knowledge is definite and unchangeable, they see it as being revisable and evolving, and that better mirrors the work of scientists and engineers (Schwarz et al., 2017).

In this practice students are defending, evaluating, critiquing and revising their own ideas that they have constructed about a concept. This step should occur when students have multiple ideas or are lacking enough evidence to clearly understand a concept they are learning. To begin this practice students must first have an argument, or a claim, that they are ready to share. It is important that students see their claims as revisable and worth questioning. Students should be ready to support their claim with evidence from their own investigations and research. Once students have shared their claim they then begin to evaluate each other's claims. At its core, this part of the practice simply means students are sharing whether or not they agree with the claim, and why or why not. Sometimes this moves into counterarguments, in which an alternative to the claim is being discussed (NRC, 2012).

Afterwards students may move into the reconciliation process. This is where students come to a conclusion about a single claim that they all believe. In this process it is important that students consider all of the evidence, and everything they know about the scientific concept in question. It is also worth a mention that sometimes no reconciliation will be met. It is possible that there are multiple correct answers, especially in the case of engineering. Whether or not students end up with the same claim, it is important that they take steps towards reconciliation, as this is how students begin to construct knowledge on the topic (Schwarz et al., 2017).

When beginning to implement this in the classroom teachers should realize that this practice begins with a fundamental shift on how teachers and students view science knowledge. This requires the viewpoint of science knowledge as being revisable, something that is worth collaborating on, and something that can explain a phenomenon. Establishing this shift amongst students is an important part in implementing this practice. Students might not be used to or comfortable with evaluating others' claims as well as the uncertainty of evolving ideas, so the classroom culture needs to be a welcoming environment for this kind of conversation. One way to do this is to allow students to have these conversations in small groups where they may be more confident. After working in small groups then come back together as a large group to share out. Another way to promote this culture is to encourage students to question teacher ideas. Modeling this at the teacher level can be very powerful for students, as it shows how scientists of all levels depend on this practice (Schwarz et al., 2017).

Obtaining, Evaluating, and Communicating Information

This practice is the final of the NGSS's SEPs. It aims to reflect the work that scientists and engineers spend over half of their time doing: obtaining, evaluating, and communicating information. This process first involves students obtaining information through various sources. It is important that students are gathering information from multiple types of sources as well as different outlets of sources. After that, they need to evaluate those sources. They are looking for information that is scientifically credible and relevant to their topic of study. Once they have gathered enough credible and relevant information they are then communicating that information in various forms. They could present their information in a diagram, graph, model, chart, equation, etc (Schwarz et al., 2017).

As noted above, there are many skills involved in this practice. The first part, obtaining information, involves students having a knowledge of how to research. The second part, analyzing information, means that students will need to be able to read and interpret scientific information. In this step they will need to have background knowledge of different scientific disciplines and symbols. In the third part, communicating information, students will have to produce scientific related texts or artifacts that persuade their audience. That being said, the best way that students can improve these skills is to continually have opportunities to practice these skills in their k-12 science education (Schwarz et al., 2017).

There is an evolution to each of the skills in this practice that should progress through students' formative years. As far as obtaining information goes, this can begin at a young age by having students viewing age appropriate, trustworthy scientific resources that have been provided to them. As they grow older they can begin to learn how to find those sources themselves. As they grow even older, they may begin to conduct interviews and search for other types of media sources like videos and photographs (Schwarz et al., 2017).

Students may begin to interpret scientific information and engineering related information at a young age by first comparing and contrasting types of sources and then discussing features of each. In this step, it can be very helpful for teachers to model how they do this in their own lives. As students grow older it is important that they continue to have practice with evaluating sources, and eventually they will work towards evaluating the relationship between the source and their topic of study (Schwarz et al., 2017).

Finally, students can begin communicating information with more structured activities at first. They can also practice giving presentations at different points in the investigative process and to different audiences. From there they are able to reflect on the situation based on audience or purpose. As students grow they can begin to try different forms of communication, such as speeches or drawings. They will work their way into more scholarly sources as they grow older and continue to practice these skills. In this step, reflection on each part is very important (Schwarz et al., 2017).

One big thing that teachers can do when implementing this practice is to provide support when it comes to reading and comprehending a scientific text. This is the first step in the practice, and it is important for students to be confident in it. Teachers can support students in this way by providing them with graphic organizers, modeling annotation techniques and summarizing strategies, and including questions to guide students through a specific text (Schwarz et al., 2017).

Transitioning to the NGSS

Implementation

Implementing the NGSS and the SEPs is a shift in the way teachers think about and teach science concepts. One of the most influential pieces to this shift is making sure that teachers have had proper training (NRC, 2014). In addition to proper training teachers also need to be provided with adequate resources and ample time to reflect on these standards and how to implement them. (Deverel-Rico & Heredia, 2018).

While planning for these units will look different, as a lot of the planning is made day by day and is dependent on student input, there is one strategy that could make planning easier. That is to come up with a claim you want students to get to by the end of the unit. That way, when students are making decisions and designing investigations, the teacher knows what the desired outcome is and can nudge students towards making decisions that will best lead to the desired outcome. (Deverel-Rico & Heredia, 2018).

Another useful tip for implementing these standards is for the teacher to try out the lessons on themself and colleagues. This can allow the teacher to get a sense of where students may take the investigations. It will also give the teacher a sense of what materials might be needed for student investigation. (Deverel-Rico & Heredia, 2018).

Collaboration is another key theme with the NGSS. One strategy that seems to work for improving student confidence with collaboration is to have students work in small groups before sharing out in a larger group. To hold students accountable for their work in a group, the teacher can allow students to use data gathered from investigations on the summative assessments. This will motivate students to be an active, collaborative participant in their group. (Deverel-Rico & Heredia, 2018).

Finally, teachers should know that this shift is going to take time, trial and error. When implementing these practices for the first time it can feel like the pace of the class is too slow, but teachers should be reminded that the pace is slower with these standards. Students are actively engaging in the science practices to learn more and ultimately it will reap more rewards than speeding through science content. They are learning to be scientists as well as learning about science ideas. (Deverel-Rico & Heredia, 2018).

Chapter Two Summary

The science and engineering practices of the NGSS are a framework of skills that students can use to help them better understand a scientific phenomenon. There are different strategies that are helpful when implementing these practices into the classroom. However, it seems like the most useful piece is repetition and uniformity on what these practices look like across grade levels, so that students are continuing to evolve in their ability to think and work like a scientist or engineer. It is very important that teachers have had adequate training in order to best be able to implement these standards. In the next chapter of my capstone project I will discuss the specifications of my capstone project.

Chapter Three

Chapter Three Introduction

This capstone project was designed to address the question, *How can teachers best implement the Next Generation Science and Engineering Practices to facilitate engaging and effective science instruction in an 8th grade classroom?* For the project portion of my capstone I have designed a unit that aligns with the following Minnesota 2019 K-12 Science Standards and Benchmarks:

- **1.2.1 Students will be able to design and conduct investigations in the classroom, laboratory, and/or field to test students' ideas and questions, and will organize and collect data to provide evidence to support claims the students make about phenomena.**
  - 8P.1.2.1.1 Plan and conduct an investigation of changes in pure substances when thermal energy is added or removed and relate those changes to particle motion.
  - 8P.1.2.1.4 Plan and conduct an investigation to determine how the temperature of a substance is affected by the transfer of energy, the amount of mass, and the type of matter.
- **3.2.2 Students will be able to use their understanding of scientific principles and the engineering design process to design solutions that meet established criteria and constraints.**
  - 8P.3.2.2.3 Design, construct, and test a device that either minimizes or maximizes thermal energy transfer.

The curriculum I developed is centered around the physical science disciplinary core ideas (DCI) of *matter and its interactions* and secondly the physical science DCI of *energy*. While there is a DCI focus in the curriculum, there is also an emphasis on students using the NGSS science and engineering practices (SEPs) to develop their science skills while gaining a deeper understanding of the science concept being taught.

In chapter three of this capstone I will be identifying the framework, setting, audience and timeline for this project. I will also expand on the lessons and assessment I chose to include as part of my curriculum.

Framework

This series of nine lessons was created to align with the NGSS three dimensional framework and the 2019 Minnesota K-12 Science Academic Standards. These lessons were designed for a grade 8 classroom and focus on the physical science concepts related to matter interactions and transfer of energy. Specifically, in this curriculum, there is a focus on using the SEPs to guide students in achieving each of the learning objectives. The goal of this curriculum is to be an example and a resource for teachers to use when making the transition to the 2019 Minnesota science standards. It includes a series of structured lessons that aim to effectively teach students following the NGSS philosophy and the 2019 Minnesota science standards. Along with the lessons are worksheets, slideshows and other resources that teachers will be able to use with students. Many of the templates used in the sample unit are versatile documents that can be modified slightly and used for other student investigations following the NGSS model.

Setting and Audience

This curriculum is meant to be used with eighth grade science students in Minnesota. I plan on teaching this unit with my eighth grade students once the new standards go into effect, although some of the template I used in this sample unit I have already been using with my current students in preparation for the change in standards. My school serves about 1,022 students in grades six, seven and eight. Ethnically and socioeconomically, this school is not very diverse. According to the Minnesota Report Card (2021), 83.8% of students are white and 9.7% qualify for free or reduced meals (Minnesota Department of Education, 2021).

The students in my school take the Minnesota Comprehensive Assessment (MCA), a statewide standardized test, when they are in eighth grade. This includes a math, reading and science section. Students take the MCA for math and reading in both sixth and seventh grade, however eighth grade is the first time since fourth grade that they take that assessment for Science. When looking at the 2018-2019 school year, the last normal year prior to the COVID-19 pandemic, 49.6% of students were proficient in the science portion of the MCA, compared to the state average of 42.4% for the 2018-2019 school year (Minnesota Department of Education, 2021). However, when looking at that same school year (2018-2019), the number of students achieving proficiency on the math portion of that exam was 62.6%, while the state average was 55.0%. In that same year, 64.9% of our students were proficient in the reading portion of the MCA and the state average was 57.6% (Minnesota Department of Education, 2021).

While standardized testing is not always the most reliable and accurate picture of student achievement, it can be informative to analyze this data. For the 2018-2019 school year students at my school scored higher than the state average in all three subject areas.

However, the proficiency percentages for math, 62.6%, and reading, 64.9%, were close to each other, and both significantly higher than the percentage of proficient students on the science portion of the test, 49.6%. That being said, the percentage of proficient students for the state in math, 55.0%, and reading, 57.6%, were both similar to each other and significantly higher than the state proficiency percentage for science, 42.4%, (Minnesota Department of Education, 2021).

Based on my own interpretations of the data, the significant difference between the performance of students in math and reading compared to the performance in science suggested that it might have something to do with the science curriculum at my school. However, the fact that the same trend appears in the statewide data suggests that this could just be the product of an exceptionally difficult science test for the year. Although, when analyzing prior years testing data, this general trend appears to stay true.

This data highlights two things, students are underperforming in science at my school and at the state level. While this can be attributed to many different factors, it does highlight the need for a strong science curriculum within both my school and the state of Minnesota as well.

Lessons

The sample unit plan I have created contains nine lessons. Many of these lessons involve students using the science and engineering practices to learn the science material. In the lesson plan there are several templates that can be used for many different science investigation or engineering design processes. Each of these templates I designed on my own.

The lessons in this unit focus on investigating thermal heat transfer. Students will begin by investigating to-go cups and the design features that make them good at storing thermal energy. This idea was inspired by OpenSciEd's curriculum, more specifically Unit 6.2 *Thermal Energy Transfer*. OpenSciEd's curriculum was designed for sixth grade students and follows the NGSS Middle School standards. That being said, it is similar to the 2019 Minnesota Science Standards, but not identical. Many aspects of the lessons in this unit have been inspired and modified from OpenSciEd's curriculum to be more developmentally appropriate for eighth graders and to better align with the 2019 Minnesota Science Standards (OpenSciEd, 2021).

Assessment

Assessment is an important part of any curriculum. In this unit plan, assessment occurs in different ways. The teacher should be assessing students' understanding of both the science concepts and their proficiency of the science and engineering practices. This can happen through informal and formal assessment. Informal assessment should be used throughout the unit to ensure that all students are meeting the learning goals as the unit progresses. Informal assessment includes teacher observations, informal checks or quick exit tickets. Through informal observations, teachers should be focusing on the question: *what do my students know about this topic, what misconceptions do my students have on this topic?* Teachers use informal data to make decisions about teaching (Barell, 2012).

Formal assessment includes both formative and summative grading. Formative work describes the work that students are doing to learn the required material. This work is exploratory and allows students to gather knowledge on the topic. Formative work should be worth a small percentage of the students' grade, if any. It is meant to be more of a tool for students to gain knowledge and to reflect on their own knowledge, while also being a tool for teachers to better understand where the students are at in terms of understanding the material. Summative assessment is when students are showcasing what they have learned in the unit. In my sample unit the summative assessment comes at the end of the unit and it is a chance for students to demonstrate their understanding of the standards being taught (Barell, 2012).

In my unit plan I incorporated both formative and summative assessments. Some of these assessments are on science concept knowledge, while others are on ability to conduct the science and engineering practices. The assessment section in my unit plan has been adapted to clearly reflect what assessments are on conceptual science knowledge and which are on the science and engineering practices.

Timeline

I created the lesson plan template in February and March of 2022. When creating this curriculum I worked backwards, by identifying the essential question I want my students to understand at the end of the unit. My design process was inspired by the Understanding by Design (UbD) framework. The unit plan documents and lesson plan documents used in my capstone project were inspired and modified from the UbD unit and lesson plan template (Bowen, 2017). The individual lesson plans were inspired by the 5E lesson planning template(Smith, 2017). The storyline at the beginning of the project document was written based on the NGSS's storyline model (Next Generation Science Standards. 2021).

While the new MN science standards were published in 2019, they will not be implemented into my school until the 2022-2023 school year. Additionally, due to the nature of the change and the fact that sixth grade and eighth grade are essentially swapping content areas, this change will happen with a “trickle up” effect. This means that the implementation will start with sixth grade in September 2022, the following year sixth and seventh grade will be adhering to the new standards, and finally, in the 2024-2025 school year eighth grade will be aligning to the new standards. That being said, I will not be able to use this unit plan with my students until then.

Chapter Three Summary

In this chapter I highlighted the need for a strong science curriculum at my school. I have described an overview of what my sample unit plan is focused on, for what audience, and in what setting. I have shared which standards my sample unit plan aligns with and how I used the UbD framework to work backward in creating my unit plan. I have also identified the types of assessments being used in my unit plan. In chapter four of my capstone paper I will be reflecting on the entire capstone process and including the limitations of my work.

Chapter Four

Chapter Four Introduction

In this final conclusion chapter I will reflect on my experience throughout this entire capstone journey. I will begin by first discussing the writing process and all that it entailed. In the next section, I will talk about the major learning I walked away with after completing my project. From there I will discuss the resources and literature that I found to be most helpful for me when working through my capstone curricular project. Next, I will go through the project limitations and implications. Finally, I will wrap up by reflecting on how I intend to use this work in the future as an eighth grade science teacher in the state of Minnesota.

The Writing Process

The goal of this capstone project was to answer the following question, *How can teachers best implement the Next Generation Science and Engineering Practices to facilitate engaging and effective science instruction in an 8th grade classroom?* In chapter one of this project I explained the need for Minnesota science teachers to have background knowledge of the Next Generation Science Standards (NGSS) and especially the Science and Engineering Practices (SEPs) that go along with those standards. In 2019 Minnesota came out with new science standards that are similar to the NGSS, which is the reason for the need to have an understanding of these practices, as they are exactly the same in the 2010 Minnesota Science Standards.

As I began writing chapter two of the project, I started by researching best practices to incorporate these standards into a classroom. After completing my research and compiling that information into a literature review, I was able to begin my capstone project. My project is a unit plan that mapped out a series of nine lessons aligned to three of the 2019 Minnesota Science Standards. The curricular unit I designed is meant to be an exemplar for 8th grade teachers in the state of Minnesota as they begin to implement the 2019 Minnesota Science Standards. I believe this exemplary work is especially important because, while the MN standards closely resemble the NGSS, they are not the same. The big difference between the MN 2019 Science Standards and the NGSS are the disciplinary core ideas (DCIs). Not all of the Minnesota eighth grade standards follow the same disciplinary core ideas as they are written in the NGSS and because of this difference it is hard to find curriculum and support that align with the 2019 Minnesota standards, which makes this work so important.

In this final chapter, chapter four, of my capstone project I will discuss the major outcomes that I walked away from this project with. I will then discuss what literature I found to be the most helpful in guiding me through my capstone project. Afterwards I will talk about the major limitations of this project and finally I will discuss how I will use this work as I progress through my teaching career.

Major Learnings

As I worked through the lesson planning portion of my curricular unit, I constantly found myself struggling to make worksheets for guiding students through the investigations. It was difficult for me to find ways to make the worksheets vague enough that all students in the class could be doing slightly different investigations without feeling like I was creating a worksheet that lacked content and direction. After thinking on this for some time I decided that instead of trying to make several worksheets for all the investigations in this unit I should just make one universal worksheet that can act as a guide for any science investigation. As I thought about the value of having a universal template I realized how manageable that would make instruction, and how valuable it would be for students in learning how to actually conduct the practices. This was a turning point in my project, as it not only makes this less time consuming for the teacher, but the universal investigation template also allows students to continually practice the SEPs in a familiar format.

In creating the first template I learned that less is actually more in this style of teaching. So, after I completed the NGSS Investigation Template, I also developed a claim writing template and model making template, all of which are universal. In creating these templates I used what I had learned from my research about incorporating the SEPs into a classroom. What I think is great about these templates is that they are vague enough to be used with many different science concepts and repeated throughout the year. They focus on guiding students in correctly using the SEPs as a tool to learn the science concepts. I feel these templates can be used by teachers of all different science levels, with slight modifications, to support student growth beyond one school year. In the future, I imagine creating more of these universal templates to help students to better conduct the Science and Engineering Practices.

Valuable Literature and Resources

In doing my research I relied on the book, *Helping Students make sense of the World using the Next Generation Science and Engineering Practices* (Schwarz et al, 2017). Many of the ideas and information that influenced my unit plan come from that text. I felt this book was helpful for explaining the why behind the NGSS's Science and

Engineering Practices as well as provide examples and strategies that teachers could use in their classroom.

Another resource that strongly influenced my work was the Next Generation Science Standards website (Next Generation Science Standards, 2022). They have countless resources available on their site that are helpful and informative on how to successfully implement these strategies.

Finally, as I began my capstone project, I discovered the OpenSciEd website (OpenSciEd, 2022) and curriculum. This is a place to find free resources available online for teachers and districts to use. OpenSciEd develops curricular units that follow the Next Generation Science Standards, and all resources are available on their website. As I began the lesson planning process of my capstone project I found it incredibly helpful to go to their website for ideas. While the standards they are following are not identical to the 2019 Minnesota Science Standards, they are close, so I was able to find similar standards and get ideas on activities to include in my curricular unit.

Implications and Limitations

As a current Earth Science teacher, one area I found myself struggling with throughout the capstone project process was general background knowledge on the science content these standards cover. This is not a field of science that I am very comfortable with, so I found myself having to learn a lot more about the science content being taught. This realization was eye opening for me, as I will need to do quite a bit of preparation before I begin teaching these standards in my classroom. As I continue to grow in my physical science content knowledge I am sure these lessons will be modified.

When it comes to the science and engineering practices themselves, I felt that the practice of “analyzing and interpreting data” was another area I do not have a comfortable amount of background knowledge in. As I reflected on those parts of my lesson plans I realized they were lacking in student direction and support. Whenever students are “analyzing and sharing data” in the lessons I prepared, they are simply sharing their investigation results on a whiteboard and reading through the data to look for patterns and similarities. As I begin to implement this style of teaching into my own personal classroom, I would like to work on better supporting students in the process of “analyzing and interpreting data.” This might be coming up with guiding questions to probe student thinking, or a short template that helps students better sift through class data.

Another limitation for this project was the fact that I have not been able to use these lessons with my students yet. In the Spring of 2022, the time of writing this, I am still teaching earth science to my eighth grade students. Because of the trickle up aspect this transition of standards requires, eighth grade science in my school will not align to the 2019 Minnesota Science Standards until the 2023-2024 academic year. That means I will not be able to use this curricular unit with my students until then. As I start to use these lessons with my students I know things will need to be modified and altered to better support my students and more successfully teach to these standards.

Future Work

The biggest thing I am excited about after conducting this capstone process is the use of the NGSS templates I have created. Even though I will not be teaching the exact standards my lesson plans align with for the next two years, many of the templates I created are universal enough to be used with the students I teach now. This will allow me to shift the way I teach my current curriculum and to incorporate more of the NGSS style of instruction before I am required to. This immediate shift will not only help me continually learn and grow in the ways of the NGSS, but it will help my students think and act in the way of scientists.

The goal with this curricular unit was to help myself and other teachers with an example of what an NGSS unit might look like. I think of these lessons as a starting point for my teaching practice in transitioning to NGSS instruction. As I learn more about NGSS and grow in my teaching experience I realize that these lessons will be adapted and modified, but doing this initial work has made me feel more confident and educated on where science education is going in the state of Minnesota. I hope that this project might help another teacher who was in my shoes with better understanding on how to implement a new style of science teaching into their classroom.

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