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IMPACT OF MODELING PRACTICES ON MIDDLE SCHOOL SCIENCE STUDENTS

by

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A capstone submitted in partial fulfillment of the requirements

for the degree of Master of Arts in Education

Hamline University

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Abstract

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The objective of this extended literature review was to answer the question: *What is the impact of modeling practices on understanding phenomena and engaging all students in a meaningful science curriculum and pedagogy in the secondary science classroom?* Through research of current literature this paper summarizes how the Next Generation Science Standards (NGSS) uses modeling to create an engaging and inclusive learning environment for all students. The literature suggests modeling is an effective practice to promote student self-efficacy, motivation, and engagement to help students from diverse backgrounds find success and feel as though they can do science. However, the implementation of these practices comes with a shift in teacher mindset to a student centered classroom and is most effective for all students when combined with culturally responsive teaching (CRT). Research concluded that modeling is an effective practice for middle schoolers to develop a rich understanding of phenomena in the science classroom.

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CHAPTER 1: Introduction

Overview

This chapter is the introduction to a systematic literature review that strives to answer the question: *What is the impact of modeling practices on understanding phenomena and engaging all students in a meaningful science curriculum and pedagogy in the secondary science classroom?* In this first chapter, the rationale for this extended literature review is explored by the author. This is followed by the definition and explanation of key terms in the literature review, such as what Next Generation Science Standards are, what modeling in science is, what culturally responsive teaching is, and how these ideas are intertwined. Appendix A has a list of acronyms used in this capstone for reference. The guiding questions for this literature review are stated, as well as the purpose for this research in this introductory chapter.

Rationale For Research

My teaching career began in a seventh grade life science classroom, where I was able to combine my love of biology and teaching middle schoolers. One could say I had landed my dream job right out of college. In this role at my first school I learned how impactful culturally relevant teaching could be, and mentors instilled in me a value that I hold dear today: that all students are capable of learning and doing science. However, it is oftentimes the way that content is presented or that a class is structured that prevents a student from being successful in a science classroom. I held this belief as I transferred to my second school, where I also taught seventh grade science. In this new building I started to implement the practices that I valued from my first school, which honored every learner, and gave more voice and choice to students. In order to stay in the district that I was in, I needed to switch to eighth grade science. The transition to earth and space science from biology was challenging for me, as it was not the type of science I was passionate about. So instead of a passion of content in my teaching, I entered a new phase of my career, building a passion in pedagogy and how science was taught.

Through experiences teaching in my own classroom, learning about Innovation Design Engineering Organization (IDEO) practices, genius hours, the importance of student voice and choice in the classroom, I developed a passion for implementing modeling practices in a science classroom to help all students be successful. Students created models, prototypes, designs, redesigned, improved, and made predictions with models. This practice seemed to be helping students understand phenomena and feel successful in science. Originally, my capstone project was going to be a research based thesis in my classroom, implementing modeling practices and NGSS practices into a science classroom that previously had not used these practices. However, due to COVID-19, my classroom looks very different from when I started on this journey (and has changed learning models more than once), and I did not believe that I would find the same value in this research as I had initially thought in 2019 when I was planning my thesis. Therefore, I switched gears, instead choosing to focus on what the literature says about NGSS practices as many states are adopting them, particularly focusing on the science and engineering principle of modeling and how this process impacts students of all backgrounds.

Next Generation Science Standards (NGSS)

In 2019, Minnesota adopted new state standards for science that are an adapted form of the Next Generation Science Standards (NGSS) based on the NRC framework with ties and connections specifically to Minnesota (i.e. standards about Native American culture and its relationship to science in Minnesota) (Science, 2020). These standards are “braided” meaning that for each standard there is an objective, and attached to these are practices, cross-cutting concepts, and core ideas. The “braided” system of standards is referred to as the three dimensional teaching and learning model, which is the basis for the NGSS framework (NRC, 2012). These three approaches to a single standard are embedded to work together to address what should be covered in a science classroom at given levels. As a result, there emerges a three-dimensional model of teaching and learning, one that involves students going beyond just memorizing a fact as the old standards asked students to do. With this three dimensional learning and teaching model, students are asked to apply the ideas of science to their lives, solve real world problems, model science, and incorporate other disciplines. However, in moving towards this new method of teaching and learning, there is a need to address how teachers approach instruction in a classroom and best practices when it comes to implementing these braided standards. (see figure 1 below for how braiding of this three faceted standard system may be implemented).

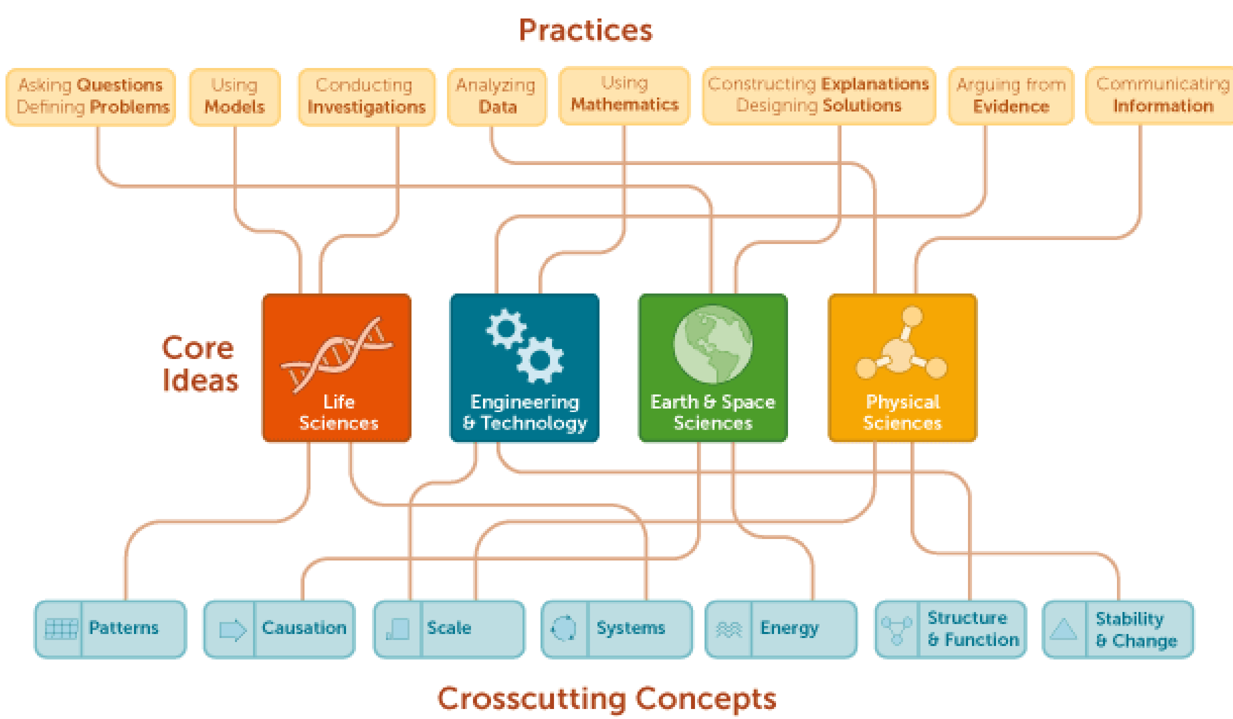

Figure 1 Graphic from The Concord Consortium https://concord.org/ngss/

The Next Generation Science Standards are relatively new to many states, particularly in Minnesota where they are adopting an adapted version of the NGSS framework standards in 2019. As more and more states are implementing this three dimensional system of standards and pedagogy, research details the need to better instruct and inform how teachers teach within this new framework (Cherbow et al., 2019; Hayes et al., 2016; Kawasaki & Sandoval, 2019; Kawasaki & Sandoval, 2020; Sherwood, 2020). Not only does the research lack an understanding of effective practices for teachers to implement this three dimensional teaching and learning, but there is also a need to better understand how this impacts student learning. There is a gap in this research of NGSS implementation surrounding how these practices impact *all* students.

Importance of Modeling

One of the key practices of the NGSS framework is using models to understand phenomena. In order to create a curriculum that matches and aligns with these new standards, a science teacher needs to understand the intersection of NGSS and research-based practices when it comes to modeling phenomena. Modeling can take a variety of different forms, verbal (i.e. analogies or metaphors) to mathematical (i.e. equations, graphs, tables), to visual (i.e. drawing, concept maps, flow charts, maps, diagrams, illustrations, etc.) to dynamic (i.e. simulations, representations) to physical (i.e. physical representations of phenomena like DNA strand) (Quillin & Thomas 2015). A model can be defined as any way to represent, communicate, predict, or understand an idea or interaction in science (Godeva & Passmore 2017; Oh & Oh, 2011; Sung & Oh, 2017; Peters & Songer, 2012; Pierson & Sherard, 2017; Quillin & Thomas 2015; Schwarz et al. 2009). Many studies of NGSS point out the importance of teaching and implementing modeling practices in the secondary classroom. However, little information is available on how to teach teachers these research-based practices to implement into their classrooms, and how this addresses motivation for all students.

Pedagogy of Middle School Science

Beyond understanding NGSS best practices when it comes to teaching and using models, it is imperative that teachers consider how this practice impacts *all* students. I have noticed in my classroom (as well as in many other science classrooms in other schools) that there is a gap between students who see themselves as “good at science” and those who see themselves as “bad at science.” I firmly believe that everyone can be good at science, for all that it requires is for a student to be curious about the world around them, and to try and explain how it works. Many humans naturally are making observations, inferences, and predictions and trying to explain the world around them and their experience on a daily basis. These practices when viewed through a scientific lens make everyone a scientist. This fundamental belief is one that a teacher of science should strive to instill in all middle school students, so that they can stop labeling themselves, and instead start to see the value they each bring to the classroom.

A large gap in academic achievement currently exists in Minnesota education between students who are white and their peers of color (Grunewald & Nath, 2019). This gap also exists along socio-economic lines, ethnic lines, gender, and levels of student engagement (Grunewald & Nath, 2019; NGSS, 2013a; NGSS, 2013b, 2013; NGSS, 2013c; NGSS, 2013d; NGSS, 2013e). For the purpose of this research, students who are disengaged are defined as students who withdraw from academic activities (Rock, 2004). This gap in student performance is alarming and speaks to the need for systemic change in how schools operate in order to serve all of their communities. Within this context, I believe there is a need for systemic change which includes changes in standards and pedagogy within the science classroom. Practices, such as the ones that

NGSS offer, might be a way to bridge this gap in student performance and understanding of science.

Guiding Questions

There is little research on the impact of scientific modeling practices, such as those described in the Science and Engineering Practices (SEPs) of NGSS on student engagement and equity practices within the middle school classroom. This literature review aims to answer the following questions about best practices in a middle school science classroom: *What is the impact of modeling practices on understanding phenomena and engaging all students in meaningful science curriculum in the secondary science classroom?* Specifically, this capstone examines the impact of modeling as an NGSS practice to assess its ability to promote understanding of phenomena to middle school students, in particular those who have historically struggled with science, in order to help science teachers develop meaningful curriculum and implement pedagogical strategies that help all students.

The extended literature conducted in chapter four serves to further investigate the intersection between practices of NGSS and Culturally Responsive Teaching (CRT) to better understand how to best teach all students science. Chapter four examines three key questions:

1. How does the NGSS Science and Engineering Practice (SEP) of “Developing and Using Models” to understand phenomena in a science classroom impact the understanding and engagement of students of color, students of low socioeconomic status, English language learners, and/or historically disengaged/struggling students?
2. How does a classroom that follows the recommendations of the NGSS framework operate to best serve student motivation and engagement in science?

3. What are the research based practices and pedagogy aligned with culturally responsive teaching and three dimensional learning strategies are most effective at promoting learning and addressing the opportunity gaps in science?

These questions serve to guide the research in the extended literature review that follows. The next section details the purpose for this study.

Purpose of Research

This research is aimed to help students of all backgrounds be successful in learning and doing science. This research has implications for meaningful practices for teachers in the middle school science field, and suggestions for how to best implement three dimensional science teaching and practices, as well as practices for CRT. The purpose of this study is to identify key practices within the NGSS SEP of modeling that have the greatest positive impact on student engagement and understanding of phenomena for a diverse group of learners. This extended literature review tries to answer the question: *What is the impact of modeling practices on understanding phenomena and engaging all students in meaningful science curriculum in the secondary science classroom?*

Conclusion

This first chapter introduces the reason for this research, and the need for it in the context of introducing new standards to states with large achievement gaps. In addition, key ideas that will be addressed throughout the literature reviews that follow were defined, such as NGSS, modeling, Culturally Responsive Teaching (CRT), and a diverse group of middle school students. This chapter concluded with guiding questions for study, and the purpose of this capstone research.

Chapter two is a literature review surrounding what existing literature is out there that addresses implementation of three-dimensional standards, like NGSS, modeling, project based learning, and how to address these ideas in a middle school classroom. Chapter three is an overview of the methods used to conduct the extended literature review that follows. Chapter four is the outcome of the extended literature review. This capstone concludes with chapter five, an analysis of where was found in the literature and next steps.

Chapter 2: Literature Review

The goal of this capstone is to research and understand what impact modeling practices have on understanding phenomena and engaging all students in a meaningful secondary science curriculum. This capstone serves to investigate the question: *what is the impact of modeling practices on understanding phenomena and engaging all students in meaningful science curriculum and pedagogy in a secondary science classroom?* The literature review that follows addresses what a meaningful science curriculum looks like, how the NGSS Science and Engineering Practice (SEP) ‘developing and using models’ is used, and how these three-dimensional teaching and learning strategies align with student motivation and engagement, and how modeling can be used as a vehicle to accomplish this. This leads to an extensive review of the literature in chapter four around how modeling and NGSS practices impact the engagement and motivation of students of color, low socioeconomic status, English language learners, or historically disengaged/struggling students. Chapter four also contains a brief discussion of the intersection of NGSS with CRT practices.

Meaningful Science Curriculum and Pedagogy

Imagine a typical middle school science classroom. Likely what a person would envision is a room with limited lab equipment, some motivational posters, Einstein on the wall, and a periodic table of elements. A teacher stands at the front of the room lecturing from a PowerPoint, showing pictures, and maybe, just maybe, a student does a laboratory experiment once a month. In this lab, the students are following a procedure that reads like a recipe and requires minimal critical thinking beyond analyzing the data.

This antiquated way of teaching science no longer has a place in the 21st century classroom. The world no longer relies on memorized information like it did in the past, but rather needs to focus on creative problem solving (NRC, 2012). In turn, this requires a shift in practices and mindsets for how science is taught within the classroom. The Next Generation Science Standards (NGSS) strive to create experiences in science classrooms where students are learning, problem solving, and coming to conclusions to create understanding (NRC, 2012).

The Next Generation Science Standards has a three dimensional approach to instruction. Each standard or objective contains a link to a scientific practice, cross-cutting concepts and a core idea. Some standards may have more than one of these ideas attached to them (Science, 2020). As the model for teaching science shifts to the NGSS framework, there is a need to reframe how teachers think of their classrooms and their approach to teaching science (Kawasaki & Sandoval, 2020). This section focuses on the best practices to implement compared to a traditional science classroom, and how these fit into learning progressions and project based learning to understand science phenomena. Finally, this section addresses how modeling (a key practice of NGSS) is integrated into understanding key phenomena in the 21st century science classroom.

Shifting to NGSS from a Traditional Science Classroom

In a traditional science classroom, there is a teacher who is viewed as the source of knowledge that they disseminate to students, and students memorize these facts and reproduce them in a test or project format. The NGSS challenges these ideas, instead focusing on a collaborative and student-centered classroom (NRC, 2012). This section details some of the barriers, challenges, and opportunities of a transition from a traditional science classroom to a NGSS science classroom, as well as a discussion of best practices in conjunction with NGSS.

One barrier to implementing NGSS in the middle school classroom is teacher mindset (Cherbow et al., 2019; Hayes et al., 2016; Kawasaki & Sandoval, 2019; Kawasaki & Sandoval, 2020; Sherwood, 2020). The NGSS strives to create a classroom where students are engaged in collaborative and authentic scientific work, where they are designing experiments about real world phenomena in order to develop, test, and refine explanations of what is going on through practicing science (NRC 2012; Sherwood, 2020). However, this goal may seem lofty, as many teachers do not have professional training around how to implement this vision of NGSS in a classroom.

The implementation of practices such as modeling, explanation, and argumentation are practices that shift a traditionally teacher centered classroom to student centered classroom. Sherwood (2020) found that many science teachers had a teacher-centered vision of their classroom prior to NGSS specific professional development. However, NGSS demands a student-centered classroom where students are engaged in discourse about real world phenomena, which in turn motivates their learning and drives instruction through practices like modeling and argumentation (Cherbow et al., 2019; Hayes et al., 2016; Kawasaki & Sandoval, 2019; Kawasaki & Sandoval, 2020; Sherwood, 2020). These practices do not work to the fullest extent in a teacher-centered classroom because students do not have voice or choice in their learning (Sherwood, 2020). In a teacher centered classroom, teachers are doing the talking. Research shows that those who are doing the talking are also doing the learning. Therefore as a shift to NGSS practices emerges, the classroom structure must shift to one that is student centered, centering the voices of students in the conversations about their learning. Sherwood (2020) raises a valid concern that "teachers may bring expectations to their inquiry-based classrooms that are entrenched in traditional practices…[that] lack student engagement in ownership of scientific ideas" (p. 588). When schools adopt NGSS, both the role of the teacher and the student must shift to be successful.

In order to create the environment where a shift in teacher role and mindset is possible, researchers (Cherbow et al. 2019; Sherwood, 2020) suggest that instruction for teachers is needed for what a successful student-centered classroom looks like, and research-based instructional practices within it. Sherwood (2020) demonstrated that with professional development around implementing NGSS in a middle school science classroom, teachers were able to shift their mindset about the teacher's role and about how science in the classroom might look and sound different. However, other studies noted that teachers maintained the mindset of a teacher centered classroom and continued to focus instruction on memorization that is associated with the old standards, hindering students' ability to create epistemic agency (Kawasaki & Sandoval, 2020). Therefore, the need for better, sustained coaching and development of teacher mindset is evident. In order to shift practices there needs to be a shift in teacher mindset and coaching for teachers on the research-based practices to implement NGSS in meaningful ways (Kawasaki & Sandoval, 2019; Kawasaki & Sandoval, 2020; Sherwood, 2020).

Kawasaki & Sandoval (2020) argue that many teachers struggle to fully translate ideas from Next Generation Science Standards and the Science and Engineering Practices (SEPs) into their classrooms. A key practice in NGSS is to promote student epistemic agency, and creating discourse in the classroom around phenomena (NRC, 2012). A part of this practice involves a student-centered classroom and investigations and opportunities to practice science and understand phenomena in the classroom (Kawasaki & Sandoval, 2020). Although teachers were given professional development training on the implementation of NGSS into the classroom, many struggled to translate these new ideas of curriculum instruction into their classroom, and in many cases their shifted ideas did not match their actions (Kawasaki & Sandoval, 2020). In order for teachers to frame a unit/learning activity, they need help in creating meaningful opportunities for students to have choice and a voice in the classroom. When redesigning these standards and learning progressions, teachers need to ensure that they have a coherent plan, and that students are held accountable by their peers and teachers (Kawasaki & Sandoval, 2019).

The NGSS framework provides four design guiding principles when planning and developing a learning progression. These principles include designing with a problem for students to solve, creating a learning environment in which students need to take responsibility for conducting investigations, holding students accountable by their peers and teacher, and finally, giving access to resources and tools for students to create their scientific explanations (Kawasaki & Sandoval, 2019). Studies around teacher implementation of these design principles illustrate that this is challenging for many teachers, as it is directly counteractive to what they have been doing for many years in a more traditional science classroom. Therefore, meaningful professional development needs to be created to help teachers implement new curricula practices (Kawasaki & Sandoval, 2019; Kawasaki & Sandoval, 2020). The current literature does not take into consideration how NGSS practices address the needs of struggling learners. This gap in the research suggests that researchers may need to further investigate the intersection of the NGSS framework and SEPs might also align with equitable practices in the classroom.

As many states are now adopting standards based on the NGSS framework, it may be important to think about how teachers are asking students to engage with content and pedagogy in the science classroom. Duschl & Bybee (2014) suggest the 5D approach to addressing elements of a classroom investigation. In this model, students are asked to decide what and how to measure/observe/sample, to develop the procedure to collect data, to record their results/observations, to create representations of their findings, and to determine if their evidence is quality, and if they need to gather more/change their experimental design (Duschl & Bybee, 2014). Students gain conceptual, procedural and epistemic knowledge about the nature of science when they are engaged in the planning and carrying out of an investigation or model (Duschl & Bybee. 2014). In framing lesson planning around these ideas, students are able to create their own experiments and create rich classroom discourse, resulting in creating a student centered space (Duschl & Bybee, 2014). In teaching students skills of discourse and practicing real world science, educators are preparing students to be successful with NGSS practices and skills that would transfer to their experiences in the rest of their lives. The NGSS framework set out to redefine how science is taught in the classroom, and in considering this transition, it may be pertinent that teachers also consider how these changes in practices are affecting student performance indicators, and different groups of students. By implementing and adopting NGSS, teachers are able to connect with a broader type of student and learner, but specific strategies in engaging all learners and creating learning communities that serve all students lack in-depth study. More research is needed to fully understand how NGSS curriculum and pedagogy impact students who are disengaged or struggle with science.

Learning Progression & Project Based Learning

A pillar of NGSS is rooting student understanding in phenomena (NRC, 2012). When students are grounded in a study of a phenomena, it can then guide the learning progression that follows. One such way that NGSS suggests presenting science curriculum is through project based and problem based learning. Problem based learning is centered around a "driving question" in which students explore and continually build on knowledge. This usually consists of a series of projects as a framework for curriculum that engages students in "in depth inquiry and construction of knowledge" (Quint & Condliffe, 2017, p. 1). Learning is scaffolded throughout a unit of study to support student learning and understanding. Project Based Learning (PBL) has been shown to have a positive effect on student engagement, motivation, and self-efficacy (Quint & Condliffe, 2017). When applied to NGSS, these practices often revolve around understanding phenomena throughout projects. There is a "driving question" or phenomena that anchors learning (NRC, 2012). As students learn, they are asked to collect evidence to shape their understanding and apply to the real world. This is a continual process, in which students start with what they knew about a phenomena or design problem when it was introduced to the end of the learning sequence when they have "figured it out" and are able to apply the SEPs to the phenomena. One of the important ways that this is done is through modeling concepts in the science classroom.

When students are asked to design a project, or engage in project based learning, they are applying real life STEM practices (Barrett et al., 2014; Hanif et al., 2019). When students are engaged in real world problem solving, not only are they addressing phenomena in science, but they are also practicing creative problem solving, and creativity in general (Barrett et al., 2014; Hanif et al., 2019). According to Hanif et al., (2019) there are three dimensions of creativity: resolution, elaboration and novelty. Each of these types of creativity were observed when students were asked to use a model (Hanif et al., 2019). Thus, Hanif et al. (2019) concluded that modeling increases student creativity and problem solving thinking skills. In the twenty-first century, students are asked to think creatively and to problem solve, therefore by modeling in the science classroom students are practicing these skills and are also given the opportunity to apply them in real world situations, preparing them for their future. When students are asked to think critically and creatively through experimentation and discussion activities, it generates positive outcomes for student understanding and creativity (Hanif et al., 2019). There is a positive impact of problem based learning and modeling practices in a science classroom that promotes creativity in students alongside collaboration, reflection, and critical thinking.

Additionally, the link between problem based learning and creativity was found by Ummah et al. (2019) in their study of manipulatives. Project based learning "facilitates students to collaborate in conceptual understanding, to apply prior knowledge, and gain skills" (Ummah et al., 2019, p. 93). Creativity is a critical skill of a lifelong learner that science teachers can promote at the secondary level. Creativity can be measured in terms of fluency, flexibility, originality & novelty (Ummah et al., 2019). Problem based learning may help motivate students by giving what they are learning in a real world context, and asking students to think creatively about solutions. This fits into the ideas that scientists use when constructing and building models to better understand and predict phenomena in order to solve real world problems. Enhancing content and understanding through the use of manipulatives (such as building models) is helpful for creating student understanding (Barrett et al., 2014; Hanif et al., 2019; Ummah et al., 2019).

Problem Based Learning (PBL) is an effective method used in science classrooms as a way to engage students in relevant and real world science practices. When interdisciplinary models and STEM based practices are incorporated into learning activities, students are able to think and engage in scientific practices in order to solve real world problems. When students are given opportunities to engage in interdisciplinary STEM activities, they are more engaged, and they walk away with a richer understanding of phenomena and better problem solving skills (Barrett et al., 2014). Engaging students in STEM activities is a way to increase student interest and engagement in science content and understanding of phenomena.

The NGSS have a focus on PBL that helps relate student understanding to experience as they address real world issues and root their understanding in phenomena. This shift in learning pedagogy also comes with a shift to performance expectations for students. Due to the fact that the SEPs are embedded within the three-dimensional standards of NGSS, students are required to engage in science practices in order to demonstrate their understanding of concepts (NGSS, 2020). Within the performance expectations, students are responsible for understanding phenomena and creating rich connections to other parts of science and their life experiences (NGSS, 2020). The way that the new standards are written (in the three-dimensional teaching and learning model), the verbage used requires students to actually do science. The juxtaposition of the new standards to the old standards in Minnesota see a shift in verbiage that moves away from memorization and towards practicing science. For instance, the words “recognize”, “identify”, and “explain” that are in the 2009 Science Standards can be done without students ever engaging in true science or engineering practices (MDE, 2009). In the NGSS framework, words such as “analyze”, “interpret”, and “apply”, as well as phrases such as “develop and use a model” and “construct an argument” are verbs that require students to actively practice and engage in doing science (NGSS, 2020). This shift in the way that the standards are written requires a change in the way that the standards are taught.

Modeling With NGSS

Many teachers do not engage students in the practices of modeling, explanation and argumentation as frequently as recommended by NGSS (Hayes et al., 2016). Modeling is a practice that is essential for scientists to use to make sense of the world, but is often only used in the science classroom as an assessment tool for students, rather than as a way for students to understand phenomena (Hayes et al., 2016). In addition, many teachers see the value of modeling as an activity, but do not appreciate the cognitive demand that this practice can also have for students. For instance, when students are able to engage in higher thinking levels, they are more engaged and leave with a greater appreciation and understanding of phenomena and real world science practices. However, in many cases, these practices of modeling are at a lower cognitive level, and not reaching the cognitive demand of NGSS (Hayes et al., 2016). There is a positive correlation between professional development training and successful NGSS implementation, demonstrating the need for instruction of teachers to best implement and shift both teacher and student mindsets and roles (Hayes et al.; Sherwood et al., 2020).

Previous studies demonstrate that when students are asked by their teacher to use modeling as a tool to understand and investigate phenomena, students gain knowledge of science and engage in critical thinking (Barrett et al., 2014; Harrison & Treagust, 2000; Lehrer & Schauble, 2006). Schwarz et al. (2009) argue that modeling is a critical part of understanding how science and the laws of nature impact students. There are four ways that students can engage in modeling practices: students can construct models, use models, compare and evaluate different models, and revise models (Bielik et al., 2018; Gouvea & Passmore, 2017; Gray & Rogan-Klyve, 2018; Pierson & Clark, 2017; Quillin & Thomas, 2014; Schwarz et al., 2009; Sung & Oh, 2018). Modeling can be used to make sense of different ideas in science and they can also be used to communicate ideas with others about phenomena (Schwarz et al., 2009). In order to best implement modeling in a science curriculum, students should engage in the four practices of modeling throughout the course of a learning sequence. Students should construct, use, evaluate and revise their models, to better understand the iterative process of science and engineering (Schwarz et al., 2009).

Teachers can evaluate how well students are engaging in modeling practices by using a learning progression and assessing their understanding on a 1- 4 leveled scale where a level 1 represents low level of understanding on Bloom's Taxonomy, and a 4 represents higher level thinking (Schwarz et al., 2009). Schwarz et al. (2009) found that most middle school students could operate modeling practices in levels 1-3 of understanding, with the potential to reach a level 4. Through learning progressions where students add to models and refine them as they gather new information, students gained a higher level of understanding through modeling (Schwarz et al., 2009). Finally, Schwarz et al. (2009) call for a change in how educators approach teaching science to better address the scientific processes that scientists engage with using models. The NGSS answers the call by giving students an opportunity to demonstrate their new learning and progress as they explore all the steps of the modeling process in order to move to higher levels of understanding of phenomena (NRC, 2012). Students can refer to their models as evidence to demonstrate their understanding of phenomena.

Research suggests that modeling is most effective when its practices are used to help students understand phenomena along the way, rather than an end product to show what the student learned (Barrett et al., 2014; Bielik et al., 2018; Gouvea & Passmore, 2017; Gray & Rogan-Klyve, 2018; Pierson et al., 2017; Quillin & Thomas, 2015; Schwarz et al., 2009). In creating a classroom where collaboration and understanding are the key practices, there needs to be an evaluation of how teachers are creating and presenting these ideas in their classrooms

(Kawasaki & Sandoval, 2020). Modeling can then become a vehicle to design a unit, adjust, and for students to better understand phenomena after multiple iterations. Sherwood (2020) noted modeling as a key practice that was challenging to implement, and also crucial in developing skills of NGSS instruction. In transitioning to the NGSS Framework, teachers may need instruction on research based practices and coaching in order to shift teacher mindset. By shifting the teacher mindset about the science classroom, teachers were able to successfully bring SEPs like modeling phenomena into the classroom to create meaningful experiences in science for all students (Kawasaki & Sandoval, 2019; Kawasaki & Sandoval, 2020; Sherwood, 2020).

This first section of the literature review serves to differentiate the NGSS framework of standards compared to previous ways in which science standards were written. In this new framework of science standards, students are asked to engage in Science and Engineering Practices (SEPs) that allow them to practice real world skills in the science classroom. The previous section details how this shift in mindset can positively impact a classroom environment and student learning. Understanding the NGSS framework, and the mindset shift required, sets up the need to then examine how these practices impact student engagement and motivation, as well as how do these practices impact all students. The second two sections of this literature review aim to address the intersection of NGSS with these two ideas: (a) student engagement and motivation; (b) how NGSS impacts all middle school science students.

Middle School Students in Science

Teaching science in middle school must focus on student learning, motivation and understanding of phenomena rather than memorizing terms for a test (Aker & Ellis, 2019; Bae & Lai, 2020; Bielik et al., 2018; Carrejo & Reinhartz, 2015; Fredricks et al., 2018; Gouvea & Passmore, 2017; Gray & Rogan-Klyve, 2018; Harrison & Treagust, 2010; Lehrer & Schauble, 2011; Peters & Songer, 2013; Pierson & Clark, 2016; Schwarz et al., 2009; Skinner et al., 2009; Smart & Marshall, 2017; Sung & Oh, 2018; Tas, 2016; Turner et al., 2014). An essential way to accomplish this goal is to have teachers who use scientific discourse and questioning in their classroom (Smart & Marshall, 2013). Middle school students deal with a wide range of emotions and emotional development during these years of school. The students in a middle school classroom all come from different cultures, family lives, socioeconomic status, and other external factors that directly impact their learning. Many argue that in the middle school science classroom it is a teacher's job to get a student engaged in science, to help them see themselves as a scientist, and to motivate students to be curious. In order to do so, a teacher must work to intrinsically motivate students by creating a student centered approach to teaching (Fredricks et al., 2017; Lee et al., 2016; Smart & Marshall, 2013). It has been shown that increasing opportunities to engage in actual science practices increases student engagement and interest in science (Bae & Lai, 2020). The following section details student motivation and engagement in middle school science students, as well as self-efficacy, with a discussion of how factors such as gender, socio-economic status, race, and ethnicity can impact students. Finally, this section concludes with research-based practices that incorporate culturally responsive teaching practices in a science classroom to address the needs of all students. The purpose of this section is to better understand the research based practices to engage all students in the middle school classroom, building off of the previous section of what NGSS is, to address the intersection of these two ideas.

Student Motivation and Engagement

Instructional methods, class characteristics, and competency have been shown to have the greatest positive impact on student engagement (Aker & Ellis, 2019). Engagement can be defined through three aspects: behavioral, cognitive and affective (Aker & Ellis, 2019; Bae & Lai, 2020; Fredericks et al., 2017; Lee et al., 2016; Tas, 2015; Turner et al., 2014). Recent research proposed that peer relationships and social settings are vital to student engagement as well (Bae & Lai, 2020). In an extensive literature review, it was noted that how a classroom was structured, method of instruction, and teacher competency had the greatest positive impact on student engagement (Aker & Ellis, 2019). These studies showed it was imperative that educators focus on what intentional instruction looks like in a middle school science classroom (Aker & Ellis, 2019). In many instances, project based learning in a science curriculum increased student engagement significantly (Aker & Ellis, 2019). With respect to middle school students, it is important to ensure that curriculum is relevant, critical, supportive of autonomy, and promotes a democratic environment in the classroom, which can impact student efficacy (Aker & Ellis, 2019).

When examining student engagement and motivation, it may be important to understand and differentiate the two terms. Lee et al. (2016) describe motivation in three ways: mastery orientation, performance approach and performance avoid. Master orientation is when a student is interested in learning for understanding, performance approach is when a student is interested in learning for a grade or reward, and performance avoid is when a student is interested in learning to avoid failure (Lee et al., 2016). Engagement on the other hand is defined as the student's behavioral, affective, and cognitive indicators (Aker & Ellis, 2019; Bae & Lai, 2020; Fredricks et al., 2017; Lee et al., 2016; Tas, 2016). In a survey of over 2,000 middle school students, intrinsic drive or mastery orientation correlated to student engagement in science classrooms, but those students characterized by extrinsic motivation of performance approach or performance avoid did not (Lee et al., 2016). Tas (2016) added a type of engagement—agentic engagement, referring to students' active contribution to the flow of a classroom, like asking questions and expressing opinions to change instruction midstream. When students were engaged in an agentic way, they were actively creating a learning environment that was better for them (Tas, 2016). The NGSS framework focuses on opportunities to engage students in an agentic way, thus creating a more positive outcome. One such way to increase student engagement is to provide students with opportunities to practice and do science, in order to better understand phenomena. Students who have more opportunities to practice science have higher engagement in the middle school science classroom (Bae & Lai, 2020). It has been well documented through research that student engagement in an area of study is a key factor to their learning and understanding of the content.

As previously stated, the three components of engagement are behavioral, cognitive, and affective, with the addition of social relations as well. Bae & Lai (2020) identified three themes for increasing student engagement: "optimally challenging opportunities designed for students to actively explore scientific phenomena", "Classroom norms and activities that prioritize peer-to-peer scientific discourse", and "supportive classroom climate characterized by positive student- and teacher-to-student relationships" (p. 1140). By implementing these practices in a science classroom, teachers were able to increase student engagement. This is a strong argument for the need for science classes to be relevant and implement these pedagogical practices along with quality curriculum and content.

In addition to the curriculum, how teachers engage in questioning within a science classroom has a direct impact on student cognitive engagement (Smart & Marshall, 2013). It was demonstrated that student cognitive engagement in the science classroom was directly related to the level of discourse used in the class - i.e. more discourse led to higher student engagement

(Smart & Marshall, 2013). Smart & Marshall (2013) determined that there was a positive correlation between the level of teacher questioning and discourse to the level of student engagement. When teachers created classrooms that were inquiry-based, they created a student centered classroom, relying on students to become cognitively engaged with the content, and facilitate discussion. In a student centered classroom, teachers are able to ask higher level thinking questions, and provide scaffolding for students to think critically and engage in practices of science in the classroom (Smart & Marshall, 2013). Therefore, when teachers focus on student justification, explanation, analysis, and prediction, they were able to develop critical thinking strategies in students, and bridged the gap between student knowledge and understanding of science concepts (Smart & Marshall, 2013).

One of the goals of NGSS is to promote science discourse and higher level thinking and questioning in the classroom in order to create an inquiry-based community. When teachers use effective questioning strategies and facilitate student led discourse in the science classroom, student cognitive engagement increases. When used in conjunction with modeling, teachers are able to ask questions such as “why did you use these materials?”, “what was your rationale for this set up?”, “what does a classmate think about your model?”, “who has an idea that could help this group with their model”, “what concepts does your model illustrate?”, “what pieces are missing from your model?”, or “what factors did you take into consideration during the construction of your model?” in order to get students to think critically and share their understanding (Smart & Marshall, 2013). This line of questioning resulted in higher levels of student cognitive engagement and overall understanding of phenomena. When a teacher engaged students in behavioral, affective, and cognitive ways, they were able to increase student motivation, leading to increased student performance in science (Smart & Marshall, 2013). If teachers are able to implement pedological practices that increase engagement through implementing NGSS, they may be better positioned to serve and engage all students.

Student engagement is directly linked to student perception of the classroom (Tas, 2016). Student perception of teacher support, student cohesion, and equity all positively contribute to student engagement (Tas, 2016). Teacher support is directly related to student outcomes, and students are likely to be more invested in their learning if they perceive that their teacher cares about them and their learning (Tas, 2016).

A study by Skinner et al. (2008) found that student engagement is positively correlated to student emotional and behavioral participation and academic success. They found that students who were more engaged were also students who had higher confidence in their abilities, higher intrinsic motivation, better self-regulation, higher learning goals, better reaction to challenges, more optimism, and more supportive relationships with adults (Skinner et al., 2008). On the other hand, students who were more disaffected (i.e. disengaged) exhibited more uncontrolled behavior and emotional strategies, were motivated by external factors, higher levels of avoidance behaviors, a greater pessimistic attitude, and negative reaction to challenges (Skiller et al., 2008). Building student emotional and behavioral participation can lead to higher levels of engagement for students. Thus, it is critical that students are taught strategies and skills that are more effective at promoting engagement, positive behaviors and positive emotional patterns to help students be successful (Skiller et al., 2008). When students believed that they cannot do something, their engagement dropped. A key practice in NGSS is to make science accessible to all students (NRC, 2012). Therefore, by creating a student centered classroom where all voices are valued, students can form positive self-identities in middle school and increase their academic engagement because of their transformed emotional and behavioral skills.

Another important finding from Skinner et al. (2008) is that students reported themselves as behaviorally engaged more than teachers found them, and that teachers often underestimated student emotional disaffection. This is significant because it points to a gap in student-teacher understanding and communication. Therefore it is important to address emotional and behavioral expectations for students and for dialogue between students and teachers to be open in order for teachers to best support their students. For instance, when students know that they are able to make mistakes and discuss ideas openly with their teacher, they are more likely to invest in a class (Skinner et al., 2008). As Skinner et al. (2008) suggested, if students believe that their teachers do not understand them (especially in middle school) they will disengage, and instead participate more in disaffected emotional and behavioral patterns, which hinders academic success.

Content delivery and engagement in science is fundamentally different from the way that students engage in other content areas (Aker & Ellis, 2019). However, there exists a gap in the literature surrounding how to engage students who are disengaged in science. A disengaged student is one who withdraws from activities in a learning environment (Rock, 2004). The best research-based instructional practices that work effectively at engaging students with science content are still largely unknown. Aker and Ellis (2019) recommend a purposeful study of disengaged students, determining which practices in a science classroom are able to change engagement for those students. Therefore it is important to understand if practices with three dimensional teaching and learning, like modeling, are effective at promoting engagement in students who are disengaged in the middle school science classroom.

Student Self-Efficacy

During the critical developmental years of middle school, students are forming their self-efficacy and their academic identities within certain subject areas (Bae & Lai, 2020). Self-efficacy is defined as "people's judgements of their capabilities to organize and execute courses of action required to attain designated types of performances" (Bandura, 1986, p. 391) Middle school is a time during which students are developing their sense of self, and research showed that often this is a point in their educational career where students start to disengage from school. How a student perceives themselves has a strong impact on their level of engagement in a particular content area. For instance, if a student perceived themselves as being "bad at science" they were less likely to be engaged in science class, and their self-efficacy decreases (Fredericks et al., 2017).

Turner et al. (2014) wanted to better understand how teachers could implement strategies for motivational instruction to increase student engagement. They found that when students were participating in learning activities that were related to four key principles of motivation (autonomy, competence, relatedness/belonging and meaningfulness), students were more likely to be engaged (Turner et al., 2014). When teachers provided a classroom where students had autonomy, competence, feelings of belonging, and meaningful learning experiences, students were more engaged (Turner et al., 2014). Teachers play a large role in creating learning communities in which students can enter what is known as their zone of proximal development when it comes to engagement. The Zone of Proximal Development (ZPD) was defined by Russian psychologist Vygotsky as "the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under guidance or in collaboration with more capable peers" (Vygotsky, 1978).

By implementing curriculum like NGSS and SEPs like modeling, researchers found that teachers were able to create a student centered classroom in which these principles were valued (Turner et al., 2014). The idea behind this is to create meaningful instruction and develop a learning community. However, as suggested by Turner et al., (2014) teachers need support to "pull up" student engagement through teaching motivational practices. It is essential that training for teachers in NGSS implementation also centers around student engagement for all learners. When teachers are not trained in how to engage students in higher level and deeper level thinking, they may fall short of delivering on the expectations and goals set forth by NGSS (NRC, 2012). Studies showed that engaging students in higher level thinking benefited all students, not just those who are already engaged, but those who are disengaged as well (Bae & Lai, 2020; Fredricks et al., 2018; Pierson et al., 2017; Quint & Condliffe, 2017; Tas, 2016). Within the context of NGSS, there also needs to be opportunities for meaningfulness, belonging, competence and autonomy in the middle school science classroom (Turner et al., 2014). Without these opportunities, student engagement decreased, and teachers were unable to create meaningful learning experiences.

Studies show that it is important for science teachers to deliver content to middle school students in ways that increase students' self-efficacy and highlights curiosity as a focus of the classroom, rather than a focus on extrinsic motivators (such as grades). Research suggests that approaches such as those found in the NGSS that work toward hands-on and minds-on science will activate student self-efficacy and increase student mastery motivation (Aker & Ellis, 2019). Through curiosity and engaging students in real world problem-solving strategies used by scientists, educators work toward increasing intrinsic motivation, self-efficacy, and student engagement in the middle school science classroom (Aker & Ellis, 2019). When thinking about science education reform, it is clear that student engagement comes from self-efficacy and a student-centered curriculum that implements real world problem-based learning that allows students to practice science skills in a way that will increase engagement and motivation, and ultimately lead to deeper understanding of scientific phenomena (Fredericks et al., 2017).

Student Socioeconomic Status, Race, Gender & Ethnicity

External factors such as race, gender, ethnicity, and socioeconomic status are also important aspects of a student experience that should be taken into consideration in the context of science education (Bae & Lai, 2020; Fredericks et al., 2017; Griner & Stewart, 2012; Shevalier & McKenzie, 2012; Skinner et al., 2009; Tas, 2016). The following subsection will address each of these factors and examine their relationship to student motivation, engagement, and overall educational experience of the student.

Researchers Fredericks et al. (2017) suggested that gender is a variable that should be considered when determining and understanding student motivation and engagement in the science classroom. For both boys and girls in a middle school science classroom, engagement increased when the class was student centered, when the content was relevant to their lives and the real world, when they could work with peers, and when they were surrounded by students that were also engaged (Fredericks et al., 2017). For girls, there was a positive correlation between a student's perceived connection with the teacher and student engagement (Fredericks et al., 2017). Tas (2016) found that student’s perceptions of learning environments positively related to their engagement in a science classroom. Female students and students with high prior achievement had higher levels of behavioral, emotional and cognitive engagement compared to male students and students who had historically low achievement. A teacher who is engaged in a classroom, invested in student understanding and who provides encouragement and scaffolding for students made a more positive impact on overall student engagement, regardless of gender. (Fredericks et al., 2017). From these studies it can be concluded that gender can be a contributing factor to student engagement in science, however, gender alone doesn't predict engagement. Research suggests that a quality middle school science classroom allows students a safe place to learn that encourages motivation, has social support, and practices relevant instructional practices.

There is currently a large gap in student achievement, learning opportunities and student engagement in science that follows socioeconomic, racial and ethnic lines (Grunewald & Nash, 2019). Due to this widening gap, there is a need to address how science instruction is implemented to increase science understanding, opportunities to engage in science practices, and overall access to science thinking. When students were given opportunities to practice and do science, they were more likely to be engaged and active in their learning (Bae & Lai, 2020). Due to this increased engagement in learning, students saw themselves as successful scientists in these classrooms. There is a significant correlation between the students who had a high number of opportunities to engage in science practices (i.e. initial knowledge, planning an investigation, conducting an investigation, and using evidence to communicate scientific data) and their engagement in the science classroom (Bae & Lai, 2020). A key factor that was identified was the social dimension of science engagement. When students were able to engage in science practices with their peers and teacher, they created positive learning communities which, as a whole, led to increased student engagement (Bae & Lai, 2020).

Schools with a higher socioeconomic status were able to engage students in more hands-on learning activities and social learning about science, with opportunities to practice these skills in the classroom, whereas schools with a lower socioeconomic status were unable to provide this same level of access to resources, and therefore had lower levels of student engagement in the science classroom (Bae & Lai, 2020). Schools with lower socioeconomic status did not have access to lab equipment, rigorous curriculum, or teachers that were fully prepared to teach science in a hands-on manner (Bae & Lai, 2020). If the achievement gap in science education is going to be addressed, the conversation needs to take into consideration the socioeconomic barriers in place. Socioeconomic barriers for schools and education are two fold: the schools overall socioeconomic status (i.e. the status of the community) and individual students' families socioeconomic status (Bae & Lai, 2020). Through this distinction, researchers can better understand how to impact schools and individual students better in terms of offering a quality science education.

When students feel as though their teachers care and are equitable, students have a higher chance of engaging in a classroom. The achievement gap points out that equity also plays a role in the conversation about classroom norms and gaps in educational opportunities. Curricula like NGSS increases student and teacher interactions, leading to higher chances to positively interact and build connections, while creating authentic engagement in a science classroom community (NRC, 2012). Tas (2016) argues that equity is key to creating an engaged classroom for *all* students. Equity in the classroom (i.e. allocation of resources, opportunities for learning, and high expectations/interest in all students) is key to increasing all student engagement (Tas, 2016). This presents the critical gap in current practices. There is a large equity gap that exists in schools, leading to a large achievement gap. Studies such as the one by Tas (2016) suggested that by addressing equity issues in the classroom educators could increase student engagement and therefore start to bridge the achievement gap.

It is clear that teaching middle school science requires a great deal of thoughtful and intentional work and planning. Not only do lessons need to address high level content, but they must also appeal to student engagement (i.e. behavioral, affective, cognitive and social), be relevant, challenging, and taught in such a way that values student input (Aker & Ellis, 2019; Bae & Lai, 2020; Skinner et al., 2009; Smart & Marshall, 2013; Tas, 2016; Turner et al., 2014). Middle school is a time where students are developing their personal identities, and need to be able to feel as though they can fail and make mistakes and still feel safe, smart and valued. Introducing a curriculum that involves scientific practices in the classroom, such as modeling, gives students a chance to process phenomena in ways that motivate and engage students. Although the principles of motivation discussed in the previous section are key for student instruction, there is little research about best practices when it comes to implementing culturally responsive teaching in the science classroom.

Culturally Responsive Teaching

For students who have been historically misrepresented or underrepresented in current curriculum and teaching practices, the changing of science standards is especially important. Since the early 2000s, research has been done surrounding the idea of Culturally Responsive Teaching (CRT). As Griner and Steward (2012) state, "[c]ulturally responsive teaching can be defined as using the cultural knowledge, prior experiences, frames of reference, and performance styles of ethnically diverse students to make learning encounters more relevant to and effective for them" (p. 589). These practices include things such as acknowledging and celebrating different cultures and ethnic groups, using a variety of different instructional strategies, providing multicultural information, resources and materials to students, and to connect home and school cultures (Griner & Steward, 2012). Research suggests that a reason for the achievement gap is partially connected to the gap between home cultures and school culture (Griner & Steward, 2012). A part of this discrepancy is that there are many teachers whose ethnicity does not reflect that of the community, leading to a divide between teacher and student culture (Griner & Steward, 2012). In attempting to bridge this divide, teachers and schools should reach out to the community and involve them to better understand their culture, to honor and bring these ideas into the classroom. When teachers were able to do this, they were able to shift their actions to create a more culturally responsive school community (Griner & Steward, 2012). When teachers created culturally responsive classrooms and learning communities, all students were better served and engaged, especially those who are racially, culturally, ethnically, and linguistically diverse.

Research identifies a key point about CRT practices that the “how” and the “what” is important, however the “why” of these practices is the heart of the matter and what gives this practice its greatest impact on students (Shevalier & McKenzie, 2012). When teachers created relationships with students from all backgrounds and encouraged all students to develop their academic and social-emotional skills they were able to create meaningful learning communities and help all students be successful. A large part of this work is to care for all students and the whole student, not just about issues such as the achievement gap (Shevalier & McKenzie, 2012). When teachers cared about students and showed those students that they cared about them, students became more motivated, and were pushed to excel in both academic and social-emotional ways. A culturally responsive teacher cares for *all* students, and demonstrated this by responding to each student in a way that promotes a meaningful and positive relationship to that individual (Shevalier & McKenzie, 2012). A teacher can do this in a science classroom through creating positive relationships with students, and by creating lessons that reflect the different cultural identities of students into their content lessons and pedagogy in meaningful ways (Ware, 2006). When teachers created lessons that intertwined student's own culture and identities, they began to bridge the culture gap between school and home and work to make a student feel as though they are successful in that particular content area (Shevalier & McKenzie, 2012). One such way that teachers can do this is through the "warm demander" pedagogy, in which teachers utilize relationships with students and high standards to help all students be successful in their classroom (Ware, 2006). Warm demanders are teachers who are viewed as authority figures, caregivers, and pedagogues in order to fit the needs of their students and keep high expectations for all students (Ware, 2006).

Another way that a culturally responsive teacher can build a positive relationship with students is through dialogue. Conversation opened up opportunities to build connections, and bridge the culture gap that exists between a student and a teacher. Effective dialogue coupled with learning about a student's culture and community went a long way to help develop meaningful lessons as well as meaningful student connections (Griner & Steward, 2012; Shevalier & McKenzie, 2012). Culturally responsive teaching also understands and promotes student-centered instruction and practices in order for students to have more control over their academic and social-emotional learning, thus enhancing their understanding and allowing them opportunities to incorporate their cultures and identities into a classroom (Griner & Steward, 2012; Shevalier & McKenzie, 2012). The goal of CRT is to teach students the development of moral principles in all students, to help all students be successful, recognized, and responded to regardless of race, ethnicity, culture, gender, or language (Shevalier & McKenzie, 2012). Therefore, when discussing middle school students, it is imperative that a teacher combines both culturally responsive and NGSS teaching practices in order to develop meaningful curriculum and pedagogy for all students.

This section served to address issues of student engagement, motivation, and student self-efficacy in the science classroom. In examining a middle school student, teachers are asked to look at the whole student, and to create spaces and places where all students are welcome and able to learn. By pairing NGSS practices and the framework of these standards with CRT practices, teachers created inclusive communities that better addressed the needs of all students. However, the literature about how successful this overlap of practices is is scarce, and needs to be better understood, which is the aim of chapter four in this extended literature review. The next section of this literature review aims to combine the ideas of the NGSS framework, what is understood as research based practices for middle school science instruction, and to understand both of these structures within the context of the NGSS Science and Engineering Practice (SEP) of modeling.

Modeling

The focus of this thesis is centered around the NGSS SEP of modeling. Modeling can be defined as "an abstract, simplified, representation of a system of phenomena that makes its central features explicit and visible and can be used to generate explanations and predictions" (Schwarz et al., 2009, p. 633). Within this broad umbrella topic of modeling, there are many different types of models that can be further categorized as verbal models, mathematical models, visual models, dynamic models, or physical models (Quillin & Thomas, 2015). Within each of these sub-categories there are specific types of models, such as graphics, equations, simulations, built structures, computer models, and several others. Regardless of the form that modeling takes place as, models can either serve as a way *of* modeling phenomena or *for* modeling phenomena

(Godeva & Passmore, 2017). The following is a discussion of the different types of models and their uses in a science classroom. To measure effectiveness of modeling in a classroom, models are categorized based on the level of understanding demonstrated throughout a learning progression (Pierson et al., 2017). By using modeling as an instructional tool, teachers can better conceptualize how students are processing information and their level of understanding of phenomena.

Modeling is a strategy used by scientists in order to make sense of the world around them and to make predictions about phenomena based on prior knowledge and models. Based on the standards for understanding science as written by the College Board and NRC, using models and modeling data is identified as a key practice for students to engage in in order to construct arguments and make predictions citing evidence (Peters & Songer, 2012). Therefore, the Next Generation Science Standards were created to address the need for more hands-on real life science occurrences in the science classroom (NRC, 2012). The NGSS puts forward practices, crosscutting concepts, and core disciplinary ideas to guide student understanding and exploration through phenomena (NRC 2012; Peters & Songer, 2012). Part of this practice is to engage students in real world science and engineering practices such as "using models" where students develop age-appropriate modeling tools, and engage in modeling practices to increase epistemological understanding.

Types of Models

Within the broad umbrella of modeling, there are various different types. Modeling can range from verbal (i.e. analogies or metaphors) to mathematical (i.e. equations, graphs, tables), to visual (i.e. drawing, concept maps, flow charts, maps, diagrams, illustrations, etc.) to dynamic (i.e. simulations, representations) to physical (i.e. physical representations of phenomena like an atom structure) (Quillin & Thomas 2015). These different forms of modeling have their places in different studies of science. For instance, Peters & Songer (2012) redesigned a climate change computer model simulation to use with middle school students to model climate change. This was an effective tool for students to study the complex and multi-faceted idea of climate change by looking at the impacts of various inputs on climate (i.e. cloud cover, pollution, sea level, etc.).

Modeling can take various forms (i.e. representation, process, pictures, diagrams, math, physical representations), and functions (i.e. describe, explain, predict, and communicate) (Oh & Oh, 2011; Quillin and Thomas, 2015; Sung & Oh, 2017). In a study by Sung & Oh (2017), middle school students engaged in expressive, experimental, and evaluative modeling to understand and explain the seasons. Through these processes students confronted misconceptions and created representations of phenomena in order to better understand what was going on. These modeling experiences created open-ended activities for students to explore phenomena, which encouraged creativity and student engagement. Students were engaged in modeling, however, they often required teacher support in order to correctly represent some aspects of the phenomena in question. When a teacher stepped in and questioned models, students were able to come to correct explanations of the seasons. By having a teacher or a peer provide feedback, students were able to adjust their models and address misconceptions (Sung & Oh, 2017). From this study, Sung & Oh (2017) concluded that modeling was a good strategy to increase student engagement and understanding, however a teacher also needed to offer help and guidance to students to create a more sophisticated level of understanding.

Researchers suggest that modeling is a great practice, especially for higher level middle schoolers, as it extends their thinking (Sung & Oh, 2017). The argument made is that a higher level processing and thinking skills used in modeling lifts all students up (Bielik et al., 2018; Gouvea & Passmore, 2017; Peters & Songer, 2013; Pierson et al., 2017; Sung & Oh, 2017). However, there is little research on how modeling practices impact students who struggle with science or who are disengaged. It is also important that teachers are trained in questioning to elicit student understanding and create discussion. Research showed that when students felt comfortable to make mistakes, and where student input was valued, students were able to help one another build on their understanding and improve their models (Bae & Lai, 2020; Smart & Marshall, 2013; Sung & Oh, 2017). Therefore the practice of modeling is just as important as the classroom community and environment to student success; both playing a crucial role in student understanding and engagement in developing an understanding of phenomena.

There are four main practices that students can engage with when using models to understand phenomenon or engineering design problems: constructing models, using models, evaluating models, and revising models (Bielik et al., 2018). Each of these practices is key to understanding the importance of modeling as a whole, and to enhancing student skills and comfort level with using models. In a study by Bielik et al., (2018) researchers analyzed the use of modeling in a seventh grade science classroom in an investigation of water quality. In this study, they identified a gap in the existing literature surrounding an in-depth analysis of how the elements of the modeling practice were used in a science classroom to best support student knowledge and modeling practice (Bielik et al., 2018). From their study Bielik et al. (2018) found that by using modeling in a series of iterations to address the issue of water quality, students were able to create high level models, and better understand the importance of the practice of modeling, in addition to developing increased knowledge around scientific phenomena. However, some students had incomplete or inaccurate models (i.e. undefined relationship, inaccurate relationship, missing variable, unconnected variable, or inaccurate label) (Bielik et al., 2018). With revision, some students were able to go back and correct these inaccuracies or add in missing information, again revealing the importance of iteration while modeling in the science classroom (Bielik et al., 2018).

Bielik et al. (2018) found that students needed direct instruction and scaffolding for the iteration of modeling, and an environment where teachers support multiple cycles of modeling in the classroom, in order for students to revise and evaluate their existing models. When students had the support to go through modeling cycles, they developed more complex and higher quality models of phenomena, which correlated to a deeper understanding of science content. Bielik et al. (2018) found that students who had a lower epistemic belief about themselves focused on surface level features of modeling, rather than how models could be used to predict or explain phenomena, pointing to the need for further study on how to engage these students and increase their epistemic beliefs in science. Furthermore, they showed that students should engage in multiple iterations of mini-modeling cycles to provide sufficient scaffolding and time to create and revise models to reflect the addition of knowledge (Bielik et al., 2018). However, there is little research about how these practices impact students who are at risk, or have a low epistemic belief system, or are disengaged in the science classroom.

Modeling tools do not exist widely at the middle school level, therefore, Peters and Songer (2012) took a model used by scientists to predict climate change and modified it to fit the needs of middle school students. Through this study, a computer program for modeling climate change was presented to a middle school classroom and evaluated and adapted to better scaffold and meet the needs of middle school science learners. With the creation of more modeling technology such as that presented by Peters and Songer (2012), students were able to model and make predictions based off of data and come to scientific conclusions and share their findings with others. This created a hands-on and minds-on setting for students to see the direct correlation between what they are learning about and what scientists around the world are also studying (Peters & Songer, 2012). With increased technology and modeling programs, there is an opportunity to engage more students with computer models to understand phenomena, draw conclusions, and make predictions.

Another way that students can model and process scientific ideas is through drawing. In science classes such as biology, drawings are incredibly important for making sense of the world and communicating understanding with other scientists. A study by Quillin and Thomas (2015) found that through scaffolding and explicit teaching of drawing as a modeling tool, students were more motivated and better understood phenomena in a biology classroom. They concluded that drawings can come from mental models which students create, and that the physical model can combine verbal and visual information together to create a representation of scientific phenomena (Quillin & Thomas, 2015).

Beyond the communication aspect of modeling, modeling through drawing can also be an important way for teachers to assess student understanding of phenomena, and also gives students a way to organize and communicate information to others (Gray & Rogan-Klyve, 2018; Lehrer & Schauble, 2011; Quillin & Thomas, 2015). Quillin and Thomas (2015) discuss how models can be both internal and external: i.e. models created in one's mind can influence the models that are then physically created through drawing or some other form of representation. Understanding these two types of models and how they interact is key to understanding how students learn and process new information.

Quillin and Thomas (2015) further examined how drawing of models can be used as different forms of scaffolding with different purposes and learning outcomes. Based on what students are asked to do, the level of understanding and level of detail in a drawing may vary (Quillin & Thomas, 2015). By drawing in science, students communicated ideas, visualized phenomena, made predictions, evaluated their work, and created new questions (Quillin & Thomas, 2015). All of these are important skills that students need to develop to be successful in science with NGSS. By drawing models, students were engaging in modeling behavior and using both cognitive effort and flexibility to reason and make sense of models (Quillin & Thomas 2015). Finally, Quillin & Thomas (2015) argue that "students' affect, or emotional state, is critical to learning success, because it influences motivation" (p. 8). Research previously discussed showed a connection between student-efficacy and motivation, so teachers may need to find engaging ways to help students believe that they can learn. Research suggests that offering students a way to express themselves through creation of a model can heighten student efficacy and thus motivation. Overall, when students' interest, value, attitude and self efficacy are high, students are more likely to become motivated to create models in order to reason through scientific phenomena (Quillin & Thomas, 2015).

Models Of vs. Models For

There are two ways in which models can be used. They can be used as representations *of* phenomena or as models *for* a certain purpose (Gouvea & Passmore, 2017; Gray & Rogan-Klyve, 2018). Models *of* a phenomenon are called canonical, whereas models that are built, revised and tested by students to understand phenomena are models *for* understanding (Gray & Rogan-Klyve, 2018). Both modeling *of* and modeling *for* have a place in the science classroom, but Gray & Rogan-Klyve (2018) argue that modeling *for* has a greater significant impact on student learning in a classroom using the NGSS framework. Gray & Rogan-Klyve (2018) found that teacher talk in framing modeling practices had a great impact on how students understood and interacted with models. They measured how teachers talked about models both implicitly and explicitly in a middle school classroom and they concluded that students needed to be explicitly taught modeling skills in the science classroom. In a study by Schwarz & White (2005), researchers found that “explicit and structured discussion about models and modeling framed around the meta-modeling knowledge framework, led to students developing a better understanding of modelling and deeper conceptual understanding of the content” (Gray & Rogan-Klyve, 2018, p. 1349). Therefore, Gray & Rogan-Klyve (2018) studied the impact of modeling talk on a middle school classroom and looked at where opportunities exist for explicit metamodeling talk during a modeling unit. They found that most of the time teachers talked about metamodeling implicitly, and there were few instances (10%) that were explicit (Gray & Rogan-Klyve, 2018). They also noticed that most of the discussion about modeling was toward the end of the unit, or at the beginning, identifying that more modeling talk could be used throughout a unit of inquiry to increase student understanding and output using models. Gray & Rogan-Klyve (2018) concluded that development of tools and routines were needed for teachers to be able to transform modeling in the science classroom from models *of* phenomena to modeling *for* understanding phenomena. It is important for teachers to discuss modeling explicitly to enhance student understanding, and identify a need to continue to teach students how to use and create models in order to add epistemological sophistication for students (Gray & Rogan-Klyve, 2018).

The importance of using models *of* phenomena vs. models *for* understanding phenomena is noted as an important difference to teach students about through a modeling inquiry unit (Gray

& Rogan-Klyve, 2018). When metamodeling talk was used in the classroom, student understanding of phenomena increased, epistemological sophistication increased, and students had a better understanding of how scientists practice science in the real world (Gray & Rogan-Klyve, 2018). Gray & Rogan-Klyve (2018) concluded that

> the development of tools and routines could better enable teachers to do the complex task of transforming disciplinary content and the practice of modeling… in the context of a model-based inquiry, into more complex and effective forms of instruction. This will better enable models to be used in the classroom as epistemic tools *for* student meaning making as opposed to merely models *of* a phenomenon. (p. 1364)

The research suggests that when teachers were trained to create units of instruction centered around inquiry using modeling, classrooms shifted from low understanding levels of creating models *of* a phenomena to higher level epistemic tools of modeling *for* understanding phenomena. (Gray & Rogan-Klyve, 2018).

The Next Generation Science Standards allows science teachers to teach students the tools that scientists use in daily practice in order to understand phenomena, referred to as the SEPs (NRC, 2012). One skill that students practice within this framework is creating and using models. Models are used as a cognitive agent for epistemic understanding of phenomenon or as representation of a phenomenon (Gouvea & Passmore, 2017). Gouvea & Passmore (2017) found that in order to increase student understanding of phenomena and move to higher levels of thinking and understanding, there needed to be a shift in the practice of the science classroom from models *of* phenomena to models *for* understanding phenomena. Models can be used in a variety of different ways, such as defining and representing what someone observes. They can also be used as a way to explain and predict phenomena, and as an epistemic tool to further scientific discovery (Gouvea & Passmore, 2017). Therefore, researchers argue that since scientists use models in these various ways in the scientific community, students should also have the ability to practice these same ideas in the science classroom. Students should be able to create models that serve to make predictions, solve problems, lead to new discoveries and understandings, and to explain phenomena (Gouvea & Passmore, 2017). When looking at modeling through an NGSS lens, there is a fundamental switch of mindset from models *of* to models *for*, which necessitates the questioning of modeling activities as follows: is there a phenomenon, is there a clear question, and is there a clear epistemic aim (Gouvea & Passmore, 2017). Gouvea & Passmore (2017) found that when students used models, they were curious, asked questions, and then used models to create understanding, explanations, and predictions of the world around them. Researchers argue that by starting with student creativity, educators are able to better position modeling *of* phenomena in the science classroom.

Levels of Understanding Within the Context of Modeling

From previous studies, it is understood that when students use modeling as a tool to understand and investigate phenomena, they gain knowledge of science and engage in critical thinking (Lehrer & Schauble, 2006). Schwarz et al. (2009) argued that modeling is a critical part of understanding how science works, and the nature of knowledge that science created over time. There are four ways that students can engage in modeling practices: students can construct models, use models, compare and evaluate different models, and revise models (Schwarz et al., 2009). Modeling can be used to make sense of different ideas in science and they can also be used to communicate ideas with others about phenomena (Schwarz et al., 2009). In order to best implement modeling in a science curriculum, students should engage in the four practices of modeling throughout the course of a learning sequence. Students should construct, use, evaluate and revise their models, to better understand the iterative process of science and engineering (Schwarz et al., 2009). Teachers can evaluate student understanding on a leveled scale from 1-4 for each criteria of the modeling process (Schwarz et al., 2009).

In the science classroom it is important that students are able to construct, use, evaluate and revise models much like scientists do in the real world, in order to better understand the scientific practice of modeling (Bielik et al., 2018). In order to engage students in these practices, teachers must include them in their classroom, which is a central idea of the NGSS framework. There is some research about how to implement modeling practices; however, there is a need to dig deeper and to better understand how modeling is used in the science classroom (Bielik et al., 2018). One particular region of interest is the gap in how modeling affects students of lower socioeconomic status, English language learners, and students with low motivation/engagement in a science classroom.

Modeling is especially important in helping to cultivate students' curiosity about science and the world around them (Lehrer & Schauble, 2011). As students learn more about scientific ideas and phenomena, their models get more and more complex, demonstrating their new understanding (Lehrer & Schauble, 2011). Teachers and students can create models at different levels of understanding that may then interact to exemplify student understanding. Modeling allows students the rare opportunity to develop materials, compare, experiment, and create predictions (Lehrer & Schauble, 2011). Lehrer and Schauble (2011) demonstrated that modeling is a key practice that helps students develop knowledge and questioning about the world around them. By using drawings as representations of ideas in biology, Lehrer and Schauble (2011) exhibited that models inspired questioning, understanding of interactions, and a greater understanding of phenomena related to ecology. Modeling was also shown to be an incredibly effective way for students to communicate with each other, teachers, and the community about their understanding of phenomena and interactions, and often lead to new forms of investigation and dialogue with students (Lehrer & Schauble, 2011). When students are led through learning progressions centered around modeling, teachers need to teach students skills of modeling in addition to the phenomena being taught (Lehrer & Schauble, 2011).

In a study by Pierson et al. (2017), researchers examined the relationship between modeling practices and students of low socioeconomic status' performance in this curriculum. They found that scaffolding along the way is essential for student understanding of modeling practices and of phenomena in science (Pierson et al., 2017). Depending on how a student believed their models were being used, their modeling practices adjusted, meaning that how a teacher structured and framed modeling practices greatly impacted students' motivation while using modeling as a tool rather than just as an end product (Pierson et al., 2017). Pierson et al. (2017) pointed out the gap in research that remains, and advised on how to support students as they develop epistemologies and practices through modeling building, especially students who are historically low-performing.

Pierson et al. (2017) adapted a set of levels of understanding progression from Schwarz et al. (2012) that demonstrated the criteria for different levels of understanding through the use of modeling. They used these criteria to demonstrate that middle school students were able to achieve in the 3-4 level of understanding through proper scaffolding and explicit instruction (Pierson et al., 2017). Pierson et al. (2017) showed that multiple modeling techniques (diagrams, physical models, and computer generated models) were all effective at promoting students' learning and understanding of modeling and scientific phenomena to a higher level. They concluded that middle school students were able to model, reason, and engage with level 4 practices and epistemologies through modeling (Pierson et al., 2017). Students were also able to use models as a way to communicate their findings, and reason at a level 4. Pierson et al., (2017) suggested that due to the student-driven nature of these modeling practices, students were able to reach a level 4 practice, therefore demonstrated that when a student centered classroom was created with real life-based modeling, students reasoned better both with phenomena and with modeling practices.

Pierson et al. (2017) found that the most successful modeling practices were when students were able to go through multiple iterations of modeling, and when scaffolding support was provided to them by a teacher. Science is a hands-on and brains-on subject, allowing students to be creative, curious and to create both epistemic and representational models to better understand the world around them. Modeling is a practice that, when used in conjunction with learning progressions, can help middle school students engage in high-level modeling performances (Pierson et al., 2017). Clearly, the use of modeling in the science classroom is an important skill, and one that requires further study in regards to effective strategies for implementation, particularly for students who have historically struggled with or have been excluded from science.

Importance of Modeling

Long before NGSS, modeling was identified as a key scientific practice that is essential for learning science in the classroom (Harrison & Treagust, 2000). In a summary of types of models, Harrison & Treagust (2000) listed ten different types of models (scale models, pedagogical analogical models, Iconic & symbolic models, mathematical models, theoretical models, maps diagrams and tables, concept-process models, simulations, mental models and synthetic models) and categorized them as analogical or personal models. Within this, models can range from concrete to abstract, and from simple to complex. Even in the 2000s, before the creation of NGSS, science teachers had identified modeling as a key tool to help students build both mental and physical models of abstract phenomena (Harrison & Treagust, 2000). However, in the 2000 and 2009 science standards, there was a focus on creating models *of* phenomena, that is, using models as solely a way to visualize concepts. The Next Generation Science Standards, on the other hand, asks students to create, design, reevaluate, and improve their own models of the world in order to make sense of phenomena. In this way, students are asked to become epistemological agents of their own learning. Although modeling has long been identified as a key tool in the science classroom, the way that educators implement this tool has shifted. The NGSS are moving away from memorizing facts of science to describing, analyzing, experimenting, and predicting phenomena (NRC, 2012).

In order to ensure that educators are providing the best science education to middle school students, teachers should be engaging students in hands-on and minds-on experiences (Carrejo & Reinhartz, 2014). Modeling allows students opportunities to use and develop cognitive skills around problem solving, while also making sure instruction is relevant and works toward students communicating ideas. When students are challenged with conceptual learning they are empowered to take control of their learning experiences and explore with curiosity, creating lifelong learners (Carrejo & Reinhartz, 2014). Building models can help reframe thinking and address misconceptions in science. As students adjust and change models, they are able to learn and improve as they go, reframing their thinking. Conceptual change is a process that takes time, and is necessary for students to engage in as they think critically about science and address their own misconceptions.

Modeling offers many opportunities for students to change their thinking (Carrejo & Reinhartz, 2014). Modeling not only engages student learners, but also challenges them to think at higher levels (Carrejo & Reinhartz, 2014; Lehrer & Schauble, 2006; Schwarz et al., 2009). Carrejo & Reinhartz (2014) concluded that

> as the eighth graders manipulated objects and built models for motion, they acquired new ideas, modified old ones, and they began to think in a new different way. As new ideas developed, they were empowered to seek answers to broader questions, and they became problem solvers and critical thinkers while building and writing stories about their models. (p. 17)

These findings support the importance of modeling as a tool in the middle school classroom to engage learners in relevant and hands-on experiences that involve real problem solving to develop a deep understanding and curiosity about the world around us.. However, little information is out there on how to teach teachers these best practices to implement into their classrooms, and how this addresses student motivation for all students.

Conclusion

This chapter synthesizes the literature and current research surrounding NGSS, middle school science students, and modeling. There is a need in the 21st century for science curriculum and pedagogy that encourages a minds-on and hands-on approach to learning. This shift in teaching practices requires a shift in classroom procedures that honors student voice and choice, ultimately creating a student centered classroom. Research points to this approach to teaching as necessary for student engagement and motivation to increase. Modeling is a pillar SEP within the NGSS framework that allows for students to experience and do real world science. This practice is student centered and helps students gain engagement, motivation, and relevant science skills.

Many studies of NGSS point out the importance of teaching and implementing modeling practices in the secondary classroom.The aim of chapter four is to dive deeper into how these practices impact *all* students, and how they can be implemented with a culturally responsive lens.What follows in chapter three is the methodology for data collection and analysis of literature for the extended literature review in chapter four.

Chapter 3: Methods

Introduction

The purpose of this study is to identify which key practices within NGSS modeling have the greatest positive impact on student engagement and understanding of phenomena for a diverse group of learners. This study aims to answer the question: *what is the impact of modeling practices on understanding phenomena and engaging all students in meaningful science curriculum in the secondary science classroom?*

The Next Generation Science Standards framework is relatively new. The National Research Council (NRC) met and published the NGSS framework in the summer of 2011 (NRC, 2012). Since its first introduction, some states have adopted the NGSS, while others have implemented an adapted version of NGSS based on the framework put forward by the NRC (NRC, 2012; NSTA, 2014). States like Minnesota have an adapted form of NGSS developed based on the recommendations in the NRC framework for K-12 Science Education in 2019 (NRC, 2012). Due to the new nature of NGSS, there is still uncertainty about effective and research based practices and pedagogy, as well as how the teacher mindset needs to shift with these new practices. The question at hand is, *what is the impact of modeling practices on understanding phenomena and engaging all students in meaningful science curriculum in the secondary science classroom?* There has been research around implementing NGSS modeling practices in middle schools, and studies have found that professional development is necessary to implement these practices the most effectively. However, little research has been done on the implementation of NGSS practices of modeling on engagement and motivation for students who are lower achieving or have additional barriers to academic success. There is also little evidence of the impacts of NGSS practices and the intersection of CRT practices in the classroom. Chapter four attempts to further examine the existing literature about the intersection of these practices and what is needed for teachers to successfully implement these in tandem.

In this chapter, the methods for a systematic literature review surrounding NGSS modeling practices, CRT, and student engagement is detailed. The need for more research is examined, and already-published research is analyzed through a series of specific metrics detailed below. The literature review that follows in chapter four is guided by the following questions:

1. How does the NGSS Science and Engineering Practice (SEP) of developing and using models to understand phenomena in a science classroom impact the understanding and engagement of students of color, students of low socioeconomic status, English language learners, and/or historically disengaged/struggling students?
2. How does a classroom that follows the recommendations of the NGSS framework operate to best serve student motivation and engagement in science?
3. What are the research based practices and pedagogy aligned with culturally responsive teaching and three dimensional learning strategies are most effective at promoting learning and addressing the opportunity gaps in science?

A systematic literature review was conducted by the author surrounding issues of modeling, NGSS, teacher mindset, equity, culturally responsive teaching, student engagement and motivation in order to answer the three questions above.

Criteria for Research

A broad range of studies were collected for this research that represent and address the different aspects of the research questions above. Studies included key findings that related to the three main research topics: middle school students, the NGSS SEP of modeling, and equity in science. The research attempted to include sources that addressed equity, student self-efficacy, motivation, engagement, and effective research based CRT and NGSS practices. The focus of these studies was to ensure that they addressed the overlap of ideas of CRT and NGSS research based practices that benefit all students.

All the studies reviewed focused on middle school-aged students or a combination of ages that included middle school students. The studies reflect a variety of different approaches and lenses to answering these questions. The studies that were examined in more detail in chapter four were recent publications, with publication dates no later than 2010. The NGSS is a relatively new set of standards (written by the NRC in 2012) therefore it is important to collect data that is representative of this implementation. Although CRT is not a new practice, it is important to include recent studies to understand the current thinking surrounding strategies to implement in a classroom and teacher mindset in an equitable and culturally responsive classroom.

Methods

Data Collection

This literature review was conducted using a variety of online databases and journals. Research was conducted and gathered from ERIC, JRST, EBSCO, & Cooperating Libraries in Consortium. Books and chapters of text were also included in this research to address the full scope of these issues.

Journals/Databases Used

Studies were located from the *Journal of Science Education*, *The Journal of the Association of Teacher Education*, *Urban Education*, *Action in Teacher Education, Journal of Research of Science Teaching, Education and Urban Society Journal of Science Education, Science & Children, Journal of Science Teacher Education, Cultural Studies of Science Education, Next Generation of Science Standards* website*, National Science Teacher, International Dialogues on Education, Journal of Educational Psychology, SAGE Publications* and *Journal of Research in Science Teaching.* Journals were located using databases such as ERIC, JRST, EBSCO and CLiC. These journals were selected because they all had to do with science education, or teaching in a diverse classroom setting.

Criteria For Inclusion / Exclusion of Studies

Research was selected based on a couple of key factors: relevancy (published within the past 10 years) and inclusion of middle school students (ranging from 6th-8th grade). Beyond this, sources had to include at least one of the following criteria: inclusion of socioeconomic status, minorities, BIPOC, or gender as a factor; student engagement or motivation; equity; culturally responsive teaching; modeling; NGSS practices.

The following keywords were used in creating initial and subsequent searches of databases and journals: “culturally responsive teaching”, “modeling”, “NGSS”, “middle school”, “equity”, “science classroom”, “English Language Learners”, “student motivation”, “student engagement”, “socio-economic status”, “gender”, “effective practices”, “inquiry-based”.

Appraisal of Studies

Studies were considered appropriate if they contained mentions of more than one of the criteria listed above. Studies were rejected if they did not address science, or did not address middle school aged students. Studies were also rejected if they were not recent in nature (i.e. published within the last 10 years). The only studies that were included were studies from journals or accredited organizations, such as NGSS. Publications included in this analysis were not limited to papers, but also include case studies, articles, and books to cover a wide variety of sources and voices surrounding these ideas.

Data Analysis

After collecting studies from various databases and journals, each literature sample was reviewed by the author. Diligent notes were taken on each study, and the author identified key phrases and ideas from each source. Papers were initially sorted into three categories, based on which main question from above they addressed (question one, two, or three). From these categories, the papers were further analyzed, and argumentation and data was collected and synthesized. Papers were also sorted based on author (and author affiliation with NGSS) to create an analysis of what the NRC claims compared to how these work in actual practice. The author used these two categorizations to create the three subsections to address what the current research says about CRT and NGSS effective practices. What follows in chapter four is the results of this systematic literature review on the impact of modeling in NGSS on engagement for *all* students in a science classroom.

Conclusion

A systematic literature review was conducted by the author surrounding issues of modeling, NGSS, teacher mindset, equity, student engagement, and motivation. Based on the studies found and the current literature that exists in this field, the following chapter is a discussion of what this extensive literature review revealed. There were three themes that will be addressed in the following chapter. First, equity in the middle school science classroom with NGSS practices, specifically looking at the impact of modeling. Second, how NGSS Science and Engineering Practices impacts student self-efficacy and how all students view themselves, motivate themselves, and understand science. Finally, what are the most effective practices in creating both a culturally responsive classroom and a classroom that implements Next Generation Science Standards.

Chapter 4: Extended Literature Review

The extended literature review that follows in chapter four aims to answer the research question: *What is the impact of modeling practices on understanding phenomena and engaging all students in meaningful science curriculum in the secondary science classroom?* At the beginning of this capstone, there were several key questions that were noted by the author that have yet to be addressed, and what follows in chapter four aims to give clarity to these questions given the available current research on these topics at this point in time. The guiding questions are as follows:

1. How does the NGSS Science and Engineering Practice (SEP) of developing and using models to understand phenomena in a science classroom impact the understanding and engagement of students of color, students of low socioeconomic status, English language learners, and/or historically disengaged/struggling students?

2. How does a classroom that follows the recommendations of the NGSS framework operate to best serve student motivation and engagement in science?
3. What are the research based practices and pedagogy aligned with culturally responsive teaching and three dimensional learning strategies that are most effective at promoting learning and addressing the opportunity gaps in science?

Chapter four is divided into three subsections in order to best address each question listed above, given the available literature surrounding the topic. Some of these questions were addressed briefly in chapter two, however, chapter four aims to dig deeper into these ideas, and more current thinking around these issues. Each subsection begins with a question that is addressed with the literature surrounding the topic. The final part of chapter four seeks to understand the most effective, research-based practices for implementing CRT and NGSS in the science classroom, drawing from recommendations from the NRC and other researchers. Chapter four concludes with a summary of key findings from the extended literature review process to address the overarching question of *What is the impact of modeling practices on understanding phenomena and engaging all students in meaningful science curriculum in the secondary science classroom?*

Impact of Modeling on *all* students

This section of the extended literature review attempts to answer the question: *How does the NGSS Science and Engineering Practice (SEP) of "Developing and Using Models" to understand phenomena in a science classroom impact the understanding and engagement of students of color, students of low socioeconomic status, English language learners, and/or historically disengaged/struggling students?* The literature surrounding the specific practice of modeling in context with historically underrepresented communities in science is lacking, and most of it stems from the NGSS case studies (NGSS, 2013a; NGSS, 2013b; NGSS, 2013c; NGSS, 2013d; NGSS, 2013e; Rodriguez, 2015). The NGSS science and engineering practice (SEP) of “Developing and Using Models” can be defined as “Use and/or develop models to predict, describe, support explanations, and/or collect data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales” (NGSS, 2013a, p. 7). This section begins with what NGSS recommends, and continues with other research based on this framework.

In Case Study One by the NGSS Release, they examined how the NGSS framework works to serve economically disadvantaged students (NGSS, 2013a). Based on a literature review and a vignette, NGSS proposed the following practices as research-based effective ways to facilitate teaching and learning for economically disadvantaged students. First, students should be able to connect their learning of phenomena to their real lives. Second, students should be able to construct and build models to represent their understanding and adjust these models as they learn more about the phenomena. Third, student discourse and teacher questioning play a large role in developing understanding for these students (NGSS, 2013a).

Case Study Two by the NRC pointed out the use of modeling as a practice in which students engaged in modeling, creating and analyzing and collaboratively refining their model as they gained a better understanding of phenomena (NGSS, 2013b). This modeling process was done in such a way where students were creating and building their models based on their cultural experiences, as well as science phenomena understanding. In Case Study Three (NGSS, 2013c) the NGSS Release argued that providing support to students who receive special education services can benefit all students, such as modeling ideas in multiple ways, and strategic grouping of students. Again, the role of teacher questioning and discourse plays a large role in student success and understanding of phenomena (NGSS, 2013c).

In every one of the vignettes and the guides created by the NGSS committee, they referenced building, using, creating, and evaluating models as a universal scientific practice that in conjunction with other effective teaching practices (such as CRT focused practices) students were able to be successful in the science classroom (NGSS, 2013a; NGSS, 2013b; NGSS, 2013c; NGSS, 2013d; NGSS, 2013e). These findings support the conclusion that modeling is an essential practice in the science classroom that can be effective for *all* students. The above case studies were performed by the NGSS writers and conducted by an equity and diversity team created by the NRC (Miller & Januszyk, 2014). It follows that they only put forth successes in implementing modeling and demonstrating how modeling is an effective practice for all students, leaving a gap in the understanding of how these practices are actually being implemented in the classroom and how effective they are when separated from the NRC group's work.

One such examination of this practice is from Marshall & Alston (2014). The NGSS calls for a shift to higher level thinking skills in the classroom through inquiry-based learning (Marshall & Alston, 2014). Marshall & Alston conducted a five year professional development series aimed at implementing inquiry-based instruction in a science classroom to understand its impact on all learners. They found that with the implementation and proper training of teachers, the use of inquiry-based learning in the science classroom increased student academic performance in science practices and concepts for all students (Marshall & Alston, 2014). Additionally, Riegle-Crumb et al. (2019) argue that with inquiry-based learning, students were able to engage more in content and lead to more in depth learning about phenomena.

Riegle-Crumb et al. (2019) studied the impact of frequent classroom activities and inquiry-based learning practices on student engagement, self-efficacy, and understanding of science and in addition studied the impact of these practices on historically underrepresented groups in the STEM fields (black, hispanic and female being their focus). Researchers found that when these groups of students were exposed to inquiry-based practices in their learning they had a more positive attitude and self-efficacy in science (Riegle-Crumb et al., 2019). Although the data that Riegle-Crumb et al. (2019) examined was from before NGSS was adopted, it still points to the value of inquiry-based learning for student self-efficacy. The NGSS framework places inquiry-based learning front and center, and could be an effective tool to help increase student self-efficacy, particularly for those students who have been historically underrepresented in the sciences. However, there is no current study that examines how effective the NGSS practices and SEPs are for all students particularly those groups that have been historically underrepresented in science fields (Riegle-Crumb et al., 2019).

Therefore, with the available literature at this point in time, it can be inferred that modeling is an effective research based SEP for all students. This suggests that modeling should continue to be used in the science classroom with inquiry-based instruction in order to address student needs. The next section builds on the idea that modeling is an effective practice and examines how NGSS practices impact student motivation and engagement for all students.

How does NGSS incorporate student motivation and engagement?

This next section of the extended literature review attempts to answer the question: *How does a classroom that follows the recommendations of the NGSS framework operate to best serve student motivation and engagement in science?* Modeling is an effective tool in the science classroom for student engagement and motivation (as noted in chapter two). This section serves to better understand how motivation and engagement differ for different students in a science classroom, and what needs to be addressed to meet the needs of all students.

Student engagement and motivation are directly tied to students self-efficacy in science and their achievement in science. Therefore, implementing quality practices in the science classroom to include all students and address their needs is necessary (Gonzales-Howard & McNeill, 2016). A key strategy to increase student motivation and engagement is through creating a classroom community and discourse (Gonzales-Howard & McNeill, 2016; Patterson, 2019). Gonzales-Howard and McNeill (2016) stated that “engagement in science practices, which are central to science discourse, is fundamental to access the science being learned and practiced in the classroom” (p. 528). Teaching science is also teaching a set of social values and norms. In a science classroom learning is dependent on teachers and students both participating and creating a social culture of learning. In order to practice the SEPs of NGSS, there needs to be inclusion of discourse and explicit teaching. As Gonzales-Howard and McNeill (2016) noted, learning science is a cultural and social endeavor.

Patterson (2019) argued that the adoption of reform-based curriculum (such as NGSS) alone does not address the inequities that exist in science education and experienced by historically underrepresented groups of students, and called for more research surrounding what effective strategies can be used to provide high quality educational experiences to these groups of students. Group work can be one way in which students engage in scientific learning and create a collaborative learning space, but it can also be a place of inequity for some students (Patterson, 2019).

Peer relationships and social hierarchies also play a large role in classroom dynamics and power structures in a classroom and should be considered when thinking about equity in education (Patterson, 2019). Patterson (2019) identified four criteria for student equity in group work: student voice, student visibility, student authority, and agency. These ideas do not work in isolation, but rather interact and create a complex system of interactions between students in a classroom (and with their teacher). As there is a shift to NGSS practices, dialogue in the science classroom and group work in the science classroom become more important. Therefore, as presented by Patterson (2019), there needs to be further study and intentionality behind how teachers give voice and power to students in order to promote equitable practices in the classroom. Patterson wrote, "...because reform-based science curriculum [i.e. NGSS] is more dialogic and generally takes place in smaller student-led groups, the successful implementation of this approach rests in a teacher's classroom organization and on students' abilities to co-construct knowledge together" (p. 376).

Patterson (2019) demonstrated that students needed to be explicitly taught how to do group work and that teachers also needed to be instructed on how to avoid the creation of social hierarchies within group work. Along with teaching NGSS, this new way of teaching science also requires teaching of social-emotional learning skills in order to address the whole student and to really dig into providing an equitable education for all students (Patterson). To create an equitable learning space in a science classroom, teachers need to place equity at the forefront of their practice and see this as a value in their classroom in the same way that they value the academic task at hand in order to help students become agents of equity (Patterson). This requires a shift in how teachers think about their classrooms, and how they teach students to interact with one another, requiring additional support and training for educators (Patterson, 2019).

Middle school is a critical time for students development of self-efficacy in science and shaping their view of themselves as a scientist (Riegle-Crumb et al., 2019). Riegle-Crumb et al. found that socioeconomic status could be a predictor of student achievement in science and self-efficacy and attitude towards science. In order to meet the needs of economically disadvantaged students, effective teaching strategies are to connect students science learning to their sense of place in their community, apply cultural practices to science, and to use project based learning and authentic questions to build understanding of phenomena (NGSS, 2013a). Throughout the case studies put forth by the NGSS council, creating a classroom community was noted and including student discourse were also noted as ways to increase student engagement and motivation in science (NGSS, 2013a; NGSS, 2013b; NGSS, 2013c; NGSS, 2013d;NGSS, 2013e).

However, Rodriguez (2015) noted that NGSS missed an opportunity to define “a dimension focusing on engaging all students, making teaching and learning more equitable, and seriously making the content more culturally inclusive” (p. 1048). Without intentionality in equity work in conjunction with NGSS, the new standards might not have the impact they hoped for to address the needs of all students (Rodriguez, 2015). Rodriguez (2015) argued that there should have also been a focus or dimension to student learning centered around ideas of engagement, equity, and diversity practices within the NGSS framework. The intersection of student engagement and motivation with CRT practices is critical here, and is discussed in more detail in the last subsection of chapter four.

Hands-on and minds-on learning such as modeling and other SEPs of NGSS have been shown to increase student engagement in science, as discussed in chapter two (Aker & Ellis, 2019; Bae & Lai, 2020; Fredricks et al., 2018; Lee et al., 2016; Quint & Condliffe, 2018; Skinner et al., 2009; Tas, 2016; Williams et al., 2018). One effective program was Science in the Learning Gardens (otherwise known as SciGL), a program funded by the National Science Foundation that aims to serve the underrepresentation of students from ethnic and racial minority groups and created a curriculum that addresses their motivational needs (Williams et al., 2018). Through aligning standards with the NGSS framework, students learned science through gardening. Williams et al (2018) found that when students engaged in gardening (an authentic and real-world science learning experience) they were more engaged in their science classes, motivated to learn, and had better learning outcomes. This suggests that creating authentic and real world experiences for students who have historically been underrepresented or excluded from science is a key way of motivating and engaging these students and seeing themselves as scientists (Williams et al).

Williams et al (2018) also argued that teacher inadequacies are a contributing factor to the widening achievement gap for students who belong to minority groups. Students develop their identities about who they are in science during early middle school, and if students leave middle school feeling marginalized and disengaged from STEM, it is likely that these students will not go on to pursue a career in STEM or further education in the field (Williams et al). They argued that an asset based approach to students must be employed by teachers in order to make meaningful change and to encourage students to feel motivated and successful in science.

Evidence from multiple sources indicates that implementing CRT and NGSS practices improves overall student engagement and motivation (Patterson, 2019; Riegle-Crumb et al., 2019; Rodriguez, 2015; Williams et al, 2018). Therefore, it is vital that the intersection between CRT and NGSS be examined through research-based practices. With research and understanding also comes the need for teacher instruction on how to best implement these practices in tandem. When students are able to receive both high quality instruction in a culturally responsive and hands-on scientific environment, they are going to be more likely to be motivated and engaged in their science classrooms, which is the ultimate goal. The next section of this extended literature serves to better understand the intersection of NGSS and CRT practices in the current literature for a science classroom.

Research-Based Practices for NGSS & CRT Intersection in the Science Classroom

The final portion of this literature review seeks to answer the question: *What research-based practices and pedagogy aligned with culturally responsive teaching and three-dimensional learning strategies are most effective at promoting learning and addressing the opportunity gaps in science?* This final section of the literature review examines the current literature surrounding the intersection of CRT and NGSS practices in the science classroom to address the needs of all learners. Modeling is one of the SEPs referenced in this section, but shall be broadened to include other inquiry-based strategies that the NGSS framework advocates for.

The NGSS Case Study Recommendations

The NRC assembled an equity and diversity team in 2013 to meet and discuss and demonstrate how the new NGSS addressed different types of learners (Miller & Januszyk, 2014). The next subsection details the findings from the five case studies, highlighting key practices identified by NGSS in terms of CRT pedagogy and SEP pedagogy in the science classroom.

Case Study One from the NRC focused on meeting the needs of economically disadvantaged students in the science classroom (NGSS, 2013a). In order to meet the needs of economically disadvantaged students, effective teaching strategies are to connect students' science learning to their sense of “place” in their community, apply cultural practices to science, and to use project-based learning and authentic questions to build understanding of phenomena (NGSS, 2013a). Throughout the vignette in Case Study One there are references to the teacher applying cultural references (i.e. comparing molecules to going to a hip-hop concert, cans on the streets, etc.) as a way to engage students and make their learning relevant to their lives, which was noted as an effective strategy (NGSS, 2013a). A large portion of Culturally Responsive Teaching is to make connections to students' lives and their understanding of how the world works. When science teachers are able to introduce phenomena that students have seen and allow for students to explore their own questions, it plays into the inherent nature of science while also creating a responsive classroom. In allowing students to explore their own culture in science class, teachers are able to make content more accessible to students and increase student engagement (NGSS, 2013a).

The NGSS framework aims to promote learning for economically disadvantaged students through project-based learning, making science relevant to students, understanding the context of science in urban and rural science communities, and empowering students to bring their own knowledge and culture to the science classroom (NGSS, 2013a). An important idea in implementation of NGSS practices is celebrating the funds of knowledge (FOK) that a student brings to the science classroom from their own life experiences (NGSS, 2013a). Case Study One identifies the socioeconomic gap as a contributing factor to the education gap that is present in many schools, however it offers little support beyond general suggestions to support these students or districts with economically challenged majorities (NGSS, 2013a). This indicates that more research is needed on the implementation of the NGSS framework on student understanding for economically disadvantaged students and schools.

In the second case study, the NRC found four key strategies as effective for targeting student learning and understanding for underrepresented groups of students. First, teaching with culturally responsive pedagogy in the science classroom. Second, getting the community involved in science learning and working through social activism in the science classroom. Third, using many different ways to represent ideas and experiences for students to learn from.

Finally, including school support systems in which students have role models or mentors of a similar racial or ethnic background to the students they are serving (NGSS, 2013b). These four key ideas were explained and expanded upon in a vignette produced by the NRC's diversity and equity team. This vignette offered an idealistic approach to what a NGSS-based classroom could look like, but did not give teachers specific tools or discuss the change in student performance through the implementation of these ideas (NGSS, 2013b). More research from sources that are not the creator of the NGSS framework are needed to determine the intersection of CRT pedagogy and NGSS pedagogy and their success rates.

Case Study Two also noted that there is a significant academic performance gap among racial groups, where black students scored on average 34 points lower than their white peers (NCES, 2012; NGSS, 2013b). In addition, there is an underrepresentation of students from racial minority groups in Advanced Placement (AP) classes, and an overrepresentation of these groups in the Below Proficient categorization in schools (NGSS, 2013b). This trend is alarming, and the gap points to a need to shift how science is taught for all students to be successful. Case Study Two pointed to four key practices to adapt pedagogy to meet the needs of ethnic and racial minority students that were noted above. However, little research has been conducted outside of the NGSS Release to support the impact that these practices have on students. This gap in the literature and the growing gap in academic achievement between ethnic and racial groups points to a need for greater intervention and more study.

Case Study Three focused on how NGSS can serve students with disabilities best (NGSS, 2013c). This case study and literature review pointed to three effective strategies to implement within the context of NGSS: first, representing ideas in a variety of ways; second, using multiple ways for students to express their learning and third, using many ways to engage students in the content. These effective and research-based practices are easy to implement within the NGSS framework, as argued by the NRC (NGSS, 2013c). Case Study Three also pointed out the achievement gap between students receiving services or accommodations for disabilities compared to their neurotypical peers (NGSS, 2013c). The presence of a gap in achievement also points to the need to revise curriculum and implement effective pedagogical practices to ensure that all students are being given a quality education. Therefore, adjusting the ways in which information is presented to students and the ways that students interact with course material that best fits their needs in order to create a learning environment of least resistance (NGSS, 2013c). These practices benefit all students, neurotypical or not, and should be considered standard practice in a differentiated or universal design classroom (NGSS, 2013c).

In Case Study Four, the NRC argued that there are five effective strategies that teachers can implement in an NGSS classroom in order to meet the needs of English language learners: (a) create literary strategies to use for all students; (b) provide language-support strategies specific to those students who are English language learners; (c) provide native language support; (d) implement discourse strategies in the classroom; (e) create connections to the home culture of those students (NGSS, 2013d). These five practices when used in combination with the NGSS framework are effective ways to narrow the achievement gap that currently exists between English language learners and their native speaking peers (NGSS, 2013d). The NGSS framework is language intensive and the science classroom demands that students engage in scientific discourse in the classroom (NGSS, 2013d). However, this can be incredibly challenging for English language learners, who are developing their language skills and are then asked to layer in a scientific discourse on top of this (NGSS, 2013d). Teachers can implement effective pedagogical strategies such as literacy supports, discourse tools, native language support and cultural connections to bridge this gap and foster student understanding of phenomena. The NGSS framework is able to focus on both meeting literacy and science goals at the same time for EL students (Miller et al., 2014).

Case Study Five focused on girls in STEM education, arguing that in order to narrow the achievement gap between the genders, teachers should implement "instructional strategies," "curricular decisions," and "classroom and school structure" (NGSS, 2013e). These are the most vague suggestions of any of the case studies. This case study argued that the most important way to raise achievement for girls in STEM is to increase student confidence (NGSS, 2013e). When girls were able to take leadership roles in the science classroom and deal with real world science practices, their engagement increased (NGSS, 2013e). There is an "experience gap" that exists between males and females for chances to do and practice science, where males have more opportunities readily available to them compared to their female peers (NGSS, 2013e). Case Study 5 argued that creating real-world and hands-on learning experiences for students at an early age can have a positive impact on girls' affinity towards science, and belief that "science is for all" (NGSS, 2013e).

The five case studies reviewed above demonstrate the need for effective CRT strategies and NGSS practices in the classroom. However, these vignettes and examples hinge largely on competent teachers who have been trained in NGSS practices *and* CRT practices. This might not always be the reality, and teachers might be underprepared to take on these large shifts in pedagogy (Kolonich et al., 2018; Lee et al., 2017; Mark et al., 2020; Marshall & Alston, 2017; Rodriguez, 2015). Without sufficient training and experience with diverse students, teachers might not be able to create a safe learning experience for students. If a teacher is insufficiently equipped to deal with the learners in front of them, they may be setting up classrooms for students to fail in because they do not have the space to be themselves, make mistakes, and understand phenomena (Kawasaki & Sandoval, 2019; Kawasaki & Sandoval, 2020; Kolonich et al., 2018). However, when teachers are trained and have shifted their mindset to a more student focused and inquiry-based classroom, a safe place for student learning is created, benefitting all (Kawasaki & Sandoval, 2019; Kawasaki & Sandoval, 2020). Therefore, this points to the need for extensive teacher mindset shifts, coaching, and implementation of three-dimensional teaching and learning practices, both in terms of NGSS and CRT effective strategies to meet the needs of these students.

These findings from the NRC equity and diversity team suggest that curriculum alone cannot do everything to close the achievement gaps that exist, but rather need effective teaching strategies within an effective framework for teaching science (NGSS, 2020). Finally, these ideas presented by the NGSS committee have an inherent bias. The NRC that put forth the findings in Appendix D, but they were also the committee that wrote and created the standards. Therefore there is an inherent bias that the standards and practices are effective, so the findings were biased in favor of this as justification. Little research has been done in actual classrooms to understand how effectively these practices of SEPs, NGSS, and CRT are being put into practice currently, and how this is currently affecting student achievement (Kawasaki & Sandoval, 2019; Kawasaki & Sandoval, 2020; Mark et al., 2020; Marshall & Alston, 2017; Miller et al., 2014; Rodriguez, 2015). The lack of understanding of the impact of these practices and the variance of student outcomes and teacher , makes it challenging to create a one size fits all model. Also due to the complexity of the NGSS and CRT it can be difficult to ensure that all teachers are doing the best that they can to create classroom spaces that are safe learning environments for all students (Kawasaki & Sandoval, 2019; Kawasaki & Sandoval, 2020; Mark et al., 2020; Rodriguez, 2015).

One thing that the NGSS Case Studies neglects is the intersectionality of these groups. What about students who are female and of color? How are they impacted? Are there better strategies to deal with intersectionality? These ideas were not addressed in the NGSS case studies, calling for the need for more research on intersectionality and effective practices in combination with NGSS practices in the science classroom. These questions are addressed later in chapter four.

Critiques of the Intersection of NGSS and CRT

Although the NRC put forth their perspective and ideas of implementation of effective pedagogy with NGSS, it is important for this literature review to also look at critiques of these practices and to understand how these practices are being implemented in classrooms across the country. Miller et al. (2014) proposed that NGSS provide a new opportunity to focus on development of science and literacy skills for all students, especially beneficial for English language (EL) students to understand scientific and language concepts in context. They found that when properly scaffolded, NGSS was successful at providing a hands-on and authentic learning experience for both language and science for EL students. Gonzales-Howard & McNeill (2016) suggest that language plays a key role in student discourse and understanding in the science classroom, particularly for English language learners. The NGSS practice of students developing a Claim Evidence Reasoning (CER) as a way to communicate ideas in science was also an effective practice for English language learners (Gonzales-Howard & McNeill). When EL students were engaged in their learning (i.e. participating more) they were able to learn more, suggesting how information is discussed in class and how students participate impacts their understanding of the material.

When students worked together in small groups they had better argumentation and a better understanding of science ideas (Gonzalez-Howard & McNeill, 2016). When students were able to work with their peers they felt safe to make mistakes, share their ideas, and often had more time to work in a smaller setting with their teacher (Gonzalez-Howard & McNeill, 2016). This suggests a need to create a safe community for all students to feel as though they can process science (written, oral, etc.). Gonzalez-Howard and McNeill (2016) found that when students could converse with others in their native language and English they had higher engagement and self efficacy. They cautioned, “in order for teachers to effectively support student engagement in science practices, they need a nuanced understanding of the role of language for constructing and communicating meaning” (Gonzales-Howard & McNeill, 2016, p. 549). As there is a shift towards the NGSS framework, teachers may need to take into consideration how content and key vocabulary terms are addressed in a classroom for EL students (Gonzales-Howard & McNeill, 2016). Many teachers are not trained in pedagogy of secondary language acquisition or bilingualism; therefore, they have little to no practices to draw on to support EL students in a mainstream science classroom, where most EL students end up (Gonzales-Howard & McNeill, 2016).

The NGSS framework strives to serve “all standards, all students” in their new framework and three dimensional approach to teaching and learning (Lee et al., 2014). Lee et al. argued that the writers of NGSS considered diversity and equity issues while creating these standards, through the creation of a diversity and equity team. These teams did a bias review of NGSS, created the case studies referenced in this chapter, created the Appendix D (which houses the case studies) and did literature reviews surrounding diversity and equity practices (Lee et al., 2014). The NGSS Diversity and Equity Team reviewed the NGSS standards to ensure that they avoided any stereotypes, and included diversity in these standards (Lee et al., 2014). The case studies in Appendix D of the NGSS framework were created and written by the NGSS Diversity and Equity Team with members who have specific expertise in each area for each case study (Lee et al., 2015). This points to the possibility that it was biased because the critiques all came from within the organization that created the standards and methods in the first place. To get a better authentic understanding of these practices in the classroom, additional research from outside sources is needed.

Another critique of the intersection of NGSS and CRT practices comes from Rodriguez (2015) where he discussed the limitations of NGSS and the challenges of implementing CRT within the NGSS framework. Rodriguez (2015) argued that by using a sociotransformative constructivism lens, that “the individual's cultural, social, historical, and academic locations cannot be separated from the what (curriculum), how (pedagogy), why (policies), and by who (teachers)” (p. 1034). In his critique of the NGSS framework, he argued that if there is going to be meaningful change in how science is taught, the current problems should be called out and addressed with specific actions in order to shift the focus to student learning, rather than the current focus on standardized test scores. Many teachers are also resistant to the pedagogical change that NGSS demands in order to be effective at creating learning spaces for all students (Rodriguez, 2015). How teachers are taught and instructed during their teacher preparation programs impacts their view of what their classroom will look like, and thus there is a need to teach how to create student-centered pedagogical classrooms and to continue to train veteran teachers in this new way of thinking in order to create meaningful change for how science is taught (Rodriguez, 2015). Rodriquez suggested that “a culturally diverse task force composed of science educators/researchers, content area scientists, teachers, curriculum specialists, administrator, and parents, should be formed and charged with developing a dimension of engagement, equity and diversity with relevant examples for each grade" (pp. 1042-1043). This task force would have the opportunity to create meaningful pedagogical practices and implement culturally relevant teaching strategies that are community- and subject-area specific, thus meeting the need for quality education for all students.

The National Science Teacher Association (NSTA) created the document "The Science Standards and Students of Color" (2017) as a way to highlight the call for equity in the science classroom that NGSS calls for in Appendix D (the case studies). In this, Strachan (2017) pointed out some culturally relevant strategies (such as high expectations and standards for all students, relationship building, creation of relevant lessons, etc.) that should be implemented in a science classroom to help all students. This document called for changes in action from teachers that were stated in 2013 when the case studies were first written, and are still not being adequately addressed in science classrooms today (Strachan, 2017). There is a need for explicit time, energy, and instruction for teachers on effective research-based practices for implementing three-dimensional learning in the classroom. Additionally, there needs to be time and energy invested in building in equitable practices to make science education accessible to all students, especially those populations who have historically been underserved in the science classroom (Strachan, 2017).

Mark et al. (2020) argued that there has been a long overdue call for work in terms of equity in the science classroom. They argue that NGSS begins to broach the topic, but does not center equity in the way that reformers demand for it to be effective (Mark et al., 2020). Mark et al. pointed out that implementation of NGSS alone is not sufficient to meet the needs of all students, rather there needs to be significant teacher training, professional development and implicit inclusion of equity practices in order to effectively work towards diminishing the science achievement gap. When equity is not addressed, there is a lack of teacher understanding, reorganization, critique of racial biases and teachers are unable to overcome these roadblocks to implementation of NGSS along equity guidelines (Mark et al., 2020). They found that none of the classroom-embedded assessments (CEAs) created by a team of teachers using the NGSS framework were designed in ways that were culturally relevant. Mark et al. (2020) recognizes that in order to be culturally relevant to students, science learning must go beyond a familiar location in a test question, and rather engage students in meaningful and authentic science experiences, which many places are not doing. In addition, they found that in less than 20% of the CEAs that were created, there was evidence of interdisciplinary integration (such as science literacy skills), provision of social resources (such as group work or peer collaboration) or student choice (Mark et al., 2020). This means that many CRT practices were not being effectively implemented or considered in teachers' approach to implementing NGSS practices in their classrooms. Mark et al. (2020) demonstrated that CRT practices and an effective equity lens could be used based on teacher current understandings to execute the NGSS, but also pointed out that there are no formal guidelines on how to do this, nor any requirements to place equity at the center of NGSS implementation. Although the practices that were used in this study incorporated equity practices, they did not match the definition of what culturally relevant teaching serves to do.

Many scholars of CRT practices advocate for an asset-based approach to teaching rather than the more traditional deficit lens in which students who have been historically underrepresented in science have been viewed (Bonner et al., 2018; Griner & Stewart, 2012; Shevalier & McKenzie, 2012; Ware, 2006). Thus, it is important to approach the implementation of CRT practices within the framework of NGSS with this asset-based approach, and to keep in mind cultural difference theory which focuses on strengths and resilience of diverse communities (Bonner et al., 2018). Bonner et al. pointed out that curriculum is a resource of CRT, and a teacher who is culturally responsive should ensure that that curriculum is meaningful and relevant to student's lives - which is what teachers are tasked with as they adopt standards from the NRC recommendations. Bonner et al. (2018) identified themes related to teacher ideas around CRT practices: "diversity enriches the classroom"; "respect, accepting and valuing of child, culture, and family, and community," teachers have a strong sense of efficacy, competence, and growing expertise in CRT," "higher achievement and graduation rates as well as increased college attendance" (pp. 707-715). The research conducted by Bonner et al. demonstrated that teachers were capable of implementing CRT practices and attitudes in their classrooms, with positive outcomes. Bonner et al. (2018) recommended that more teacher preparation programs and professional development should center CRT practices in order to shift to an asset-based approach to diverse classrooms.

The mindset of an asset-based classroom is also integral to reframing the idea of the academic achievement gap as an opportunity gap instead. Kolonich et al. (2018) suggested that the achievement gap can be instead understood as an opportunity gap, acknowledging that this gap exists due to disparities in educational opportunities that are available to different groups based on their communities. They recommended an asset-based approach to reframing thinking around science reform (Kolonich et al., 2018). Kolonich et al. argued that an inclusive classroom is one in which students and teachers attend to their differences, such as linguistic, cultural, or emotional, that they may have in the classroom. Using funds of knowledge (FOK) in science can help students feel as though they are drawing on their experiences in the science classroom, and is an asset-based approach to teaching (Kolonich et al., 2018). Kolonich et al. developed a framework with five elements to help address three dimensional learning and inclusive pedagogy. The five elements are “positions students as knowledge generators,” “elicits, values and leverages FOK”, “encourages the use and sharing of student language”, “values students’ lived experiences as evidence”, and “promotes the use of students’ critical lens to solve problems” (pp. 696-698).

In a discussion of intersectionality of NGSS and CRT, it is also important to discuss intersectionality of groups of students. This next subsection details the implications of NGSS and CRT practices for black girls. This serves to identify effective strategies for the intersection of gender and race for students in a science classroom. The NRC identified strategies such as implementing CRT practices as beneficial for students of color, but neglected to discuss the intersection of race and gender and effective pedagogy practices for these groups (NGSS, 2013b; NGSS, 2013e).

King & Pringle (2018) argue that, historically, black girls have been underrepresented in the STEM careers. There are large gaps that are persistent through gender, ethical, racial and income lines, causing students to too easily be overlooked in these categories. King & Pringle also called out how many of the reforms lack “sincere moral concern or commitment to the well-being of children of color” (p. 540). In order to authentically tackle the academic achievement gap, black female students need to be engaged in CRT practices such as counterspaces for their voices to be heard and celebrated in order to begin to bridge this gap. Counterspaces are spaces where the main function is to “challenge deficit notions that lead to self-enhancement, and ultimately, adaptive responses” and to “promote the physiological wellbeing of individuals who have been marginalized or experienced oppression” (King & Pringle, 2018, p. 542). It is imperative for teachers to provide a safe space where students feel like they can express themselves and learning can happen. Currently, there are no spaces like this for black girls. Often, black girls do not feel welcomed in a science classroom, and often experience racism and sexism in these places, in addition to being underestimated by their teachers and counselors in terms of their academic abilities (King & Pringle). King & Pringle (2018) argue that in order to increase the inclusion and participation of black women in STEM, a "culture of science and science teaching must be transformed to one that values girls, students of color, and those who come from low socioeconomic households" (p. 546). This points to a need for study of intersectionality in the classroom and to shift teacher mindset and classroom cultures to value all voices and backgrounds and celebrate funds of knowledge.

When black girls were able to engage in spaces where the science they learned directly connected to their lives, their interests, and their community, they felt empowered, encouraged, and increased their science self-efficacy (King & Pringle, 2018). When black girls had teachers who built authentic relationships, challenged students to think critically and creatively, made science relevant to their lives, and built a community of scientists, the students were more engaged, and had a higher self-efficacy in science (King & Pringle, 2018). All of these are CRT strategies that can be employed with NGSS, but the intersection of these has yet to be described and studied in depth. King & Pringle (2018) concluded that black girls became more engaged and interested in STEM after authentic hands on experiences, that they continued to develop agentic engagement in science, and that black girls identified race rather than gender or socioeconomic status as having the greatest influence over their learning experiences in science. Teachers have the power to incorporate these findings into the NGSS and therefore into the science classroom, creating authentic and meaningful experiences for all students, and providing students with opportunities to practice SEPs in the classroom. Although this study did not look specifically at NGSS practices, it did highlight the importance of the NRC recommendations for teaching science and their impact on black girls.

The requirement for inclusion of studies in this literature review was that they were published recently (within the past 10 years). Even with this criteria, there are gaps in the existing literature about widespread impacts of NGSS practices and effective teaching strategies for historically underrepresented groups in STEM fields. This suggests that there is a greater need for more specific research to be done in this area, and especially in understanding the implementation of the NGSS framework with effective culturally responsive teaching strategies to impact all learners. There is still research that needs to be done in order to better understand how specific culturally responsive practices and strategies can be used in the science classroom to include all students in learning. Further study is needed to also understand how teachers are being instructed to carry out authentic science experiences and CRT practices to close the opportunity gap.

Conclusion

Researchers have clearly articulated that understanding the intersection of CRT and NGSS practices is important as the standards continue to change and be implemented. The implication of this research is important for many science classrooms as our spaces become more diverse, full of all kinds of learners from all different backgrounds and funds of knowledge. Teachers need to be trained in ways to address and help all students learn science.

What preceded in chapter four was an extended literature review, diving deeper to answer the research questions:

1. How does the NGSS Science and Engineering Practice (SEP) of developing and using models to understand phenomena in a science classroom impact the understanding and

engagement of students of color, students of low socioeconomic status, English language learners, and/or historically disengaged/struggling students?

2. How does a classroom that follows the recommendations of the NGSS framework operate to best serve student motivation and engagement in science?
3. What are the research-based practices and pedagogy aligned with culturally responsive teaching and three-dimensional learning strategies that are most effective at promoting learning and addressing the opportunity gaps in science?

These questions stemmed from the initial research by the author in chapter two, in order to better understand the intersection of CRT and NGSS in the current literature. Chapter five addresses the answers to these research questions and offers the author's analysis and recommendations for future use and research.

Chapter 5: Conclusion

Introduction

The purpose of this final chapter is to synthesize the information in the previous two literature reviews and draw final conclusions. This extended literature review capstone project seeks to answer the question: *What is the impact of modeling practices on understanding phenomena and engaging all students in meaningful science curriculum in the secondary science classroom?* Chapter two defined key terms and identified some effective practices, but did not address the intersection of these topics. Chapter four attempted to break down these ideas to answer three overarching questions.

The literature review in chapter two summarized the current understanding of Next Generation Science Standards (NGSS) practices and Culturally Responsive Teaching (CRT) practices. There is agreement that the hands-on and inquiry-based approach of NGSS standards helps students find relevance, self-efficacy, and increases student engagement in science (Bielik et al., 2018; Gouvea & Passmore, 2017; Kolonich et al., 2018; Lee et al., 2017; Mark et al., 2020; Marshall & Alston, 2017; NGSS, 2013a; NGSS, 2013b; NGSS, 2013c; NGSS, 2013d; NGSS, 2013e; Patterson, 2018; Riegle-Crumb et al., 2019; Rodriguez, 2015). It is also noted that CRT practices such as connecting to student communities, culture, and what they bring to the classroom are also important for student motivation, self-efficacy, and performance in a science classroom (Griner & Stewart, 2012; Mark et al., 2020; Marshall & Alston, 2017; Shevalier & McKenzie, 2012). Chapter two also went into detail of the benefits of the NGSS Science and Engineering Practice of modeling as a tool to incorporate both CRT and NGSS pedagogy. However, there exists little research about the intersection of CRT and NGSS practices and pedagogy and their impact on all students. The author intended to do more specific research of the SEP of modeling and CRT practices, however, there was little literature and research on this specific topic, so the search was broadened to inquiry-based learning practices, which includes modeling.

The extended literature review in chapter four attempted to answer these questions, and identify the impact of the overlap of CRT, and the NGSS SEP of modeling on all students' self-efficacy, performance, and motivation in science. The NGSS put forth their own set of case studies in 2013 to support that the NGSS practices were culturally relevant and worked for the majority of students in the studies (NGSS, 2013a; NGSS, 2013b; NGSS, 2013c; NGSS, 2013d; NGSS, 2013e). However, as argued in chapter four, these case studies were inherently biased due to their creation through the organization that also wrote the standards, and there has been little further research by others to corroborate these findings. This suggests that although there may be a meaningful connection, more direct research is needed on student engagement, performance, and self-efficacy when teachers implement both CRT and the Science and Engineering Practices of NGSS in a science classroom. Based on current research, the NGSS practices of modeling and other real life application of science is beneficial to many diverse groups of students. However, this is also contingent on adequate teacher preparation and training in both CRT and NGSS practices and pedagogy in order for them to be effective.

What follows in this chapter are final thoughts and conclusions about the literature review. This chapter begins by detailing the new findings and learning from the research conducted, followed by a discussion of the implications of these findings on current practices. Afterwards, the limitations of this study are addressed, followed by the author's recommendations for future research. Finally, this capstone concludes with benefits to the profession.

New Learning

Based on the extensive literature review in chapters two and four the author puts forth the following answers to the research questions. The first broad and overarching research question was: *What is the impact of modeling practices on understanding phenomena and engaging all students in meaningful science curriculum in the secondary science classroom?* Based on the literature reviews conducted, the author concluded that modeling is an effective practice in engaging middle school students in meaningful science practices and knowledge building. Modeling allows students to interact with phenomena in a hands-on and minds-on way that allows for a deeper understanding of scientific concepts. This tangible learning helps students who have historically struggled with science or groups who have been historically underrepresented in science, and makes the content more accessible to all students. Modeling in science can be a vehicle for CRT practices and pedagogy. Students are able to engage in real world phenomena, access their Funds of Knowledge, build on each other, engage in meaningful discourse, and build relationships with their teacher and peers. However, as the literature suggests, in order for these practices to be meaningful, teachers need explicit teaching, instruction, and coaching about how to implement NGSS and CRT pedagogy in their classrooms.

With this initial question answered, I wanted to better understand what CRT and NGSS practices and pedagogy I could bring to my classroom to adjust my instruction to be more meaningful for all students. I also wanted to understand where and what the intersection of CRT and NGSS is, and what others have found to be successful. This led to the creation of the guiding questions for chapter four.

Question one: How does the NGSS Science and Engineering Practice (SEP) of developing and using models to understand phenomena in a science classroom impact the understanding and engagement of students of color, students of low socioeconomic status, English language learners, and/or historically disengaged/struggling students? Question one attempted to understand the impact of modeling on these specific groups of learners. As noted in chapter four, modeling was shown to be an effective practice for all of these groups of students. This led the author to create more lessons and base more of their instructional teaching on the NGSS SEP “developing and using models” to support student understanding of phenomena. When students are engaged in authentic, hands-on, real world science learning, all students benefit and take away a richer understanding of phenomena. This leads to a group of students who can problem solve, think critically, and work together in order to prepare them for their futures. Based on the literature available, the author concluded that modeling in the science classroom is an effective practice for all students to benefit from.

Question two: How does a classroom that follows the recommendations of the NGSS framework operate to best serve student motivation and engagement in science? This research question sought to clarify the intersection of modeling and NGSS with student motivation and engagement. From the studies examined in both chapter two and chapter four, there was a clear connection between hands-on learning opportunities (such as modeling) and student engagement and motivation. The literature is clear that when students are able to do science, their self-efficacy increases as well as their motivation and engagement in science class. These are important findings as schools shift to NGSS implementation, and start to embed these practices into their classrooms.

Question three: What are the research based practices and pedagogy aligned with culturally responsive teaching and three dimensional learning strategies are most effective at promoting learning and addressing the opportunity gaps in science? Finally, question three began to unpack the intersection of NGSS and CRT practices, and how little actual research has been done on this topic. There were few sources outside what the NRC put forth and critiques from other researchers of these practices. Therefore, there is still research that is needed about how these two pedagogies work together and in practice. As stated in chapter four, oftentimes the NRC painted idealistic situations and classrooms, with training and coaching for teachers. I fear that the reality of implementation might be far from this idyllic picture the NRC paints. However, the overarching ideas of celebrating all students' voices, funds of knowledge, cultures, communities, and strengths is one that can be directly implemented by a teacher within the context of NGSS. Based on the existing understanding of NGSS and CRT, there needs to be time, energy, and resources devoted to training preservice and current service teachers on how to best implement NGSS and CRT in a science classroom, especially at the middle school level. This need for training should include some sort of summer workshop, coaching and prolonged mentoring of teachers to help them understand their biases, switch to an asset-based approach, and to be able to learn about what practices work best in their spaces.

From this literature review, I have a better understanding of what the framework of the NGSS suggests, especially in terms of what modeling looks like. This will make my transition to these standards in the upcoming years easier. I also have a better understanding of effective CRT practices to implement in my classroom to make my classroom more inclusive and a learning environment that is meaningful to all students. After this research, in reflecting it is clear that I have a lot of personal work on this topic to do. I have a lot of learning about what these standards are and how to teach them, while also reframing how I think about science instruction, and the role of a teacher in a science classroom. Along with this shift in standards and mindset, I must also spend time examining my own biases and current practices in a CRT lens. I know that from doing this research I am more aware of my actions and of strategies to help all students be successful in my classroom.Based on this research, I also know that districts, schools, and teachers all need additional meaningful, intentional, and prolonged professional development and mentorship for the best outcomes of incorporating CRT and NGSS.

Implications & Limitations of Study

From the findings and recommendations of the sources cited in this extended literature review it is clear that more research is needed surrounding the intersection of NGSS SEPs and CRT and the impact of these practices on all students in the science classroom. The research from the previous chapters points to a need for an in-depth study of the most effective practices of NGSS SEPs and of CRT in order to better understand their intersection in the science classroom. There is also little data to support how these practices show up on standardized test scores, and if implementation of either NGSS and/or CRT practices are effective at closing achievement gaps in science education. However, what little research does exist about the intersection of these two practices (NGSS and CRT) suggests these two practices in conjunction can be successful in increasing student achievement, motivation, and self-efficacy in science (Lee et al., 2017; Mark et al., 2020; Rifle-Crumb et al., 2019; Rodriguez, 2015).

Due to the limited current research of the intersectionality of NGSS and CRT, it is in the best interest of the science education system to create and implement policies that require teacher training, coaching, and mentoring in effective Culturally Responsive Teaching practices, and on effective ways to implement SEPs of the NGSS. Incoming science teachers should be instructed in effective and research based practices to implement in alignment with NGSS and CRT during their preservice teaching programs. This explicit instruction of CRT and NGSS effective strategies could then in turn help other veteran teachers and school communities create a three dimensional teaching and learning environment in the science classroom.The shift to a student centered classroom that NGSS and CRT strategies demand may be a dramatic shift for some teachers, which would require funding and time to teach teachers these effective practices. In order to implement these changes effectively, districts will need to invest time, energy, and resources into building on what teachers already know and do to give the best quality instruction to all of their students.

The limitations of this study include limited data from standardized test scores that include a shift to NGSS practices. This study was conducted during the 2020-2021 school year, during which the COVID-19 pandemic was wreaking havoc on the education system. This could have impacted the number of recent publications and created roadblocks for some states who were in the process of implementing NGSS practices. Another limitation of this study is that the use of the NGSS are not required in every state. In fact, only 20 states have adopted NGSS, 24 states have adopted a version of the NGSS based on the NRC framework recommendations, and six states have not adopted any version of NGSS (NSTA, 2014). Due to the lack of uniformity in science standards across the United States, it is challenging to compare how each state is meeting the needs of science education. However, each state is different and has different populations with different challenges to deal with. Although NGSS is one way to strive towards a more standard methodology of teaching science, the NRC provided a framework as a way for states to make it work for them. Due to the varied nature of science standards across states, it is also difficult to understand each state's implementation of CRT practices in the science classroom. The study of the broad US science curriculum implementation and effectiveness is beyond the scope of this literature review, however is still a vital piece for understanding the implications of NGSS and CRT practices on all students.

A final limitation of this study was the researcher's personal bias towards NGSS and a student centered classroom, as well as the benefits of modeling. Although the researcher tried to be objective, their personal views could have impacted which studies were included and excluded, the interpretation of results, and the needs for improvements as these standards are implemented in the future.

Recommendations For Future Research

Based on the research done for this extended literature review, there lacks an understanding of the intersection of NGSS and CRT practices and the most effective of both of these in the science classroom. Culturally Relevant Teaching and hands-on experiences in science are valuable for students. To what extent is still unclear. There is a need for more research to better understand how these practices are being implemented across the United

States, and how adopting the NGSS framework is shifting to a more hands-on and real world science application of phenomena in a student centered way to work to close the achievement gap. More research is needed to identify the most effective practices and how these practices are being communicated to current and preservice teachers. There is also a gap in the research about how teacher mindset affects students self-efficacy and success in a middle school science classroom. In addition, there is a lack of understanding around what types of professional development and interventions for teachers are effective for changing teacher mindset to better implement CRT and NGSS SEPs in the classroom to benefit all students. Finally, there is also a gap in understanding of intersectionality (i.e. how do multiple factors such as gender and race and socioeconomic status, etc.intersect and impact student experience) and effective NGSS practices.

Communicating Results & Benefit to Profession

As NGSS is adopted or adapted in states, understanding the limitations and challenges of implementing this change is important. This capstone serves to identify issues in this transition and to understand effective strategies for implementing NGSS and CRT practices in the middle school science classroom. Therefore, this extended literature review will be accessible to the public on the Hamline University's Digital Commons for other educators to access to understand the current thinking about NGSS and CRT practices. The results of this study were also shared with a small group in the capstone presentation.

This research benefits the profession by highlighting gaps in the current thinking and literature around implementation of effective NGSS and CRT practices in the science classroom. By pointing out the pitfalls of this understanding, teachers may be better equipped to critically examine their own practices, grow, and reflect on how these practices might need to shift as the NGSS are adopted.

Finally, I have benefitted from this research by having a better understanding of what CRT practices are effective, and how to begin to pair these with NGSS SEPs. This research also benefited coworkers as I brought these ideas to our PLC discussions and brought a new perspective as we transition to implementing the new Minnesota adapted version of the NGSS in the upcoming years. Finally, by understanding what the three dimensional learning and teaching model looks like, and the challenges for other teachers, I can begin to prepare myself and my classroom for the shift in mindset that these new standards require.

Conclusion

From this extended literature review it is clear that modeling is an effective practice to engage all learners in in order to help them understand phenomena and make sense of the world around them. However, there is also a lack of research in how the SEPs of NGSS such as modeling, intersect and overlap with a culturally responsive classroom. This points to the need for more research and a better understanding of the intersection in order to best prepare teachers in both practices. I believe that these practices are interrelated and connected, and the way that education moves forward is by creating quality and authentic learning experiences for all students. The extended literature review conducted by the author is a good first step in this process of understanding the intersection of these practices. However, there is more work that needs to be done. The real work is in the implementation of CRT and NGSS SEPs in meaningful ways for students, which I hope will be put into practice as states such as Minnesota adopt the new standards. I am moving back to my dream job, teaching 7th grade science next year, where we will transition to the new NGSS adopted standards. I will bring knowledge of research-based practices such as the SEP of modeling and CRT in order to make the classroom a more inclusive and collaborative learning space for all.

References

Aker & Ellis (2019). A Meta-Analysis of Middle School Students' Science Engagement. *International Dialogues on Education*, *6*(1), 9-24. ISSN 2198-5944

Bae, C. L., & Lai, M. H. (2020). Opportunities to participate in science learning and student engagement: A mixed methods approach to examining person and context factors. *Journal of Educational Psychology, 112*(6), 1128-1153. doi:10.1037/edu0000410

Barrett, B.S., Moran, A.L. & Woods, J.E. (2014). Meteorology meets engineering: an interdisciplinary STEM module for middle and early secondary school students. *International Journal of STEM Education* 1(6). doi:10.1186/2196-7822-1-6

Bandura, A. (1986). *Social foundations of thought and action: a social cognitive theory.* Englewood Cliffs, NJ: Prentice-Hall

Bielik, T., Opitz, S., & Novak, A. (2018). Supporting Students in Building and Using Models: Development on the Quality and Complexity Dimensions. *Education Sciences*, *8*(3), 149. doi: 10.3390/educsci8030149

Bonner, P. J., Warren, S. R., & Jiang, Y. H. (2018). Voices From Urban Classrooms: Teachers' Perceptions on Instructing Diverse Students and Using Culturally Responsive Teaching. *Education and Urban Society. 50*(8), 697-726. https://doi.org/10.1177/0013124517713820

Bybee, R. (2014). NGSS and the Next Generation of Science Teachers. *Journal of Science Education. 25*(2), 211-221. DOI: 10.1007/s10972-014-9381-4

Carrejo, D. J., & Reinhartz, J. (2014). Facilitating Conceptual Change through Modeling in the Middle School Science Classroom. *Middle School Journal*, *46*(2), 10–19. doi: 10.1080/00940771.2014.11461905

Cherbow, K., Mcneill, K., Lowenhaupt, R., Mckinley, M., & Lowell, B. (2019). Teaching Teachers: NGSS Lesson Adaptations. *Science and Children, 56*(05), 73-77. doi:10.2505/4/sc19_056_05_73

Duschl, R. A., & Bybee, R. W. (2014). Planning and carrying out investigations: An entry to learning and to teacher professional development around NGSS science and engineering practices. *International Journal of STEM Education, 1*(1). doi:10.1186/s40594-014-0012-6

Fredricks, J. A., Hofkens, T., Wang, M.-T., Mortenson, E., & Scott, P. (2017). Supporting girls' and boys' engagement in math and science learning: A mixed methods study. *Journal of Research in Science Teaching*, *55*(2), 271–298. doi: 10.1002/tea.21419

Gonzales-Howard, M., & McNeill, K. L. (2016). Learning in a Community of Practice: Factors Impacting English-Learning Students' Engagement in Scientific Argumentation. *Journal of Research in Teaching, 53*(4), 527-553. DOI 10.1002/tea.21310

Gouvea, J., & Passmore, C. (2017). 'Models of' versus 'Models for'. *Science & Education, 26*(1-2), 49-63. doi:10.1007/s11191-017-9884-4

Gray, R., & Rogan-Klyve, A. (2018). Talking modelling: Examining secondary science teachers' modelling-related talk during a model-based inquiry unit. *International Journal of Science Education, 40*(11), 1345-1366. doi:10.1080/09500693.2018.1479547

Griner, A. C., & Stewart, M. L. (2012). Addressing the Achievement Gap and Disproportionality Through the Use of Culturally Responsive Teaching Practices. *Urban Education. 48*(4), 585-621. DOI: 10.1177/0042085912456847

Grunewald, R., & Nath, A. (2019, October 11). A Statewide Crisis: Minnesota's Education Achievement Gap. Retrieved December 06, 2020, from https://www.minneapolisfed.org/~/media/assets/pages/education-acheivement-gaps/achievement-gaps-mn-report.pdf?la=en

Hanif, S., Wijaya, A. F. C., & Winarno, N. (2019). Enhancing Students' Creativity through STEM Project-Based Learning. *Journal of Science Learning*, *2*(2), 50. doi: 10.17509/jsl.v2i2.13271

Harrison, A. G., & Treagust, D. F. (2000). A typology of school science models. *International Journal of Science Education, 22*(9), 1011-1026. doi:10.1080/095006900416884

Hayes, K. N., Lee, C. S., Distefano, R., O'Connor, D., & Seitz, J. C. (2016). Measuring Science Instructional Practice: A Survey Tool for the Age of NGSS. *Journal of Science Teacher Education, 27*(2), 137-164. doi:10.1007/s10972-016-9448-5

Kawasaki, J., & Sandoval, W. A. (2019). The Role of Teacher Framing in Producing Coherent NGSS-Aligned Teaching. *Journal of Science Teacher Education, 30*(8), 906-922. doi:10.1080/1046560x.2019.1657765

Kawasaki, J., & Sandoval, W. A. (2020). Examining teachers' classroom strategies to understand their goals for student learning around the science practices in the Next Generation Science Standards. *Journal of Science Teacher Education, 31*(4), 384-400. doi:10.1080/1046560x.2019.1709726

King, N. S., & Pringle, R. M. (2018). Black girls speak STEM: Counterstories of informal and formal learning experiences. *Journal of Research of Science Teaching, 56*(5), 5339-569. DOI: 10.1002/tea.21513

Kolonich, A., Richmond, G., Krajcik, J. (2018). Reframing Inclusive Science Instruction to Support Teachers in Promoting Equitable Three-Dimensional Science Classrooms. *Journal of Science Teacher Education, 29*(8), 693-711. DOI:

10.1080/1046560X.2018.1500418

Lee, C. S., Hayes, K. N., Seitz, J., Distefano, R., & O'Connor, D. (2016). Understanding motivational structures that differentially predict engagement and achievement in middle school science. *International Journal of Science Education*, *38*(2), 192–215. doi: 10.1080/09500693.2015.1136452

Lee, O., Miller, E., & Januszyk, R. (2014). Next Generation Science Standards: All Standards, All Students. *Journal of Science Education, 25*(2), 223-233. DOI 10.1007/s10972-014-9379-y

Lehrer, R., & Schauble, L. (2006). Scientific thinking and science literacy: Supporting development in learning in contexts. In W. Damon, R.M. Lerner, K.A. Renninger, & I.E. Sigel (Eds.), *Handbook of child psychology* (6th ed., Vol. 4). Hoboken, NJ: John Wiley and Sons.

Lehrer, R., & Schauble, L. (2012). Seeding evolutionary thinking by engaging children in modeling its foundations. *Science Education*, *96*(4), 701–724. doi: 10.1002/sce.20475

Mark, S. L.., Tretter, T., Eckels, L., & Strite, A. (2020). An Equity Lens on Science Education Reform-Driven Classroom-Embedded Assessments, *Action in Teacher Education*, *42*(4), 405-421. doi: 10.1080/01626620.2020.1756527

Marshall, J. C., & Alston, D. M. (2014). Effective, Sustained Inquiry-Based Instruction Promotes Higher Science Proficiency Among All Groups: A 5-Year Analysis. *Journal of Science Teacher Education, 25*(7), 807-821. DOI: 10.1007/s10972-014-9401-4

Miller, E., Januszyk, R. (2014). The NGSS Case Studies: All Students, All Standards. *Science & Children, 51*(5), 10-13. DOI: 10.2505/4/sc14_051_05_10

Miller, E., Lauffer, H. B., & Messina, P. (2014). NGSS for English Language Learners. *Science*

& Children. 51(5), 55-59. doi: 10.2505/4/sc14_051_05_55

Minnesota Department of Education. (2009). *Minnesota Academic Standards Science K-12.* https://education.mn.gov/MDE/dse/stds/sci/

National Research Council. (2012). *A framework for k-12 science education : Practices, crosscutting concepts, and core ideas*. ProQuest Ebook Central https://ebookcentral.proquest.com

Next Generation Science Standards. (2013a). *Economically disadvantaged students and the Next Generation Science Standards*. https://www.nextgenscience.org/sites/default/files/%281%29%20Economically%20Disadvantaged%206-14-13_0.pdf

Next Generation Science Standards. (2013b). *Students from racial and ethnic groups and the Next Generation Science Standards.* https://www.nextgenscience.org/sites/default/files/%282%29%20Case%20Study%20Race%20and%20Ethnicity%206-14-13.pdf

Next Generation Science Standards. (2013c). *Students with disabilities and the Next Generation Science Standards.* https://www.nextgenscience.org/sites/default/files/%283%29%20Case%20Study%20with%20Disabilities%207-1-13.pdf

Next Generation Science Standards. (2013d). *English language learners and the Next Generation Science Standards.* https://www.nextgenscience.org/sites/default/files/%284%29%20Case%20Study%20ELL%206-14-13.pdf

Next Generation Science Standards. (2013e). *Girls and the Next Generation Science Standards.* https://www.nextgenscience.org/sites/default/files/%285%29%20Case%20Study%20Girls%206-14-13.pdf

Next Generation Science Standards. (2020). *Next Generation Science Standards*. https://www.nextgenscience.org/

NSTA. (2014). *About the Next Generation Science Standards*. NGSS @ NSTA. https://ngss.nsta.org/About.aspx#:~:text=The%2020%20states%20are%20Arkansas,Rhode%20Island%2C%20Vermont%20and%20Washington.

Oh, P. S., & Oh, S. J. (2011). What teachers of science need to know about models: an overview. *International Journal of Science Education*, *33*(8), 1109–1130. doi:10.1080/09500693.2010.502191

Patterson, A. D. (2019). Equity in group work: the social process of creating justice in a science classroom. *Cultural Studies of Science Education, 14*(2), 361-381. https://doi.org/10.1007/s11422-019-09918-x

Peters, V. L., & Songer, N. B. (2012). Evaluating the Usability of a Professional Modeling Tool Repurposed for Middle School Learning. *Journal of Science Education and Technology*, *22*(5), 681–696. doi: 10.1007/s10956-012-9422-8

Pierson, A. E., Clark, D. B., & Sherard, M. K. (2017). Learning progressions in context: Tensions and insights from a semester-long middle school modeling curriculum. *Science Education*, *101*(6), 1061–1088. doi: 10.1002/sce.21314

Quillin, K., & Thomas, S. (2015). Drawing-to-Learn: A Framework for Using Drawings to Promote Model-Based Reasoning in Biology. *CBE—Life Sciences Education, 14*(1). doi:10.1187/cbe.14-08-0128

Quint, J., & Condliffe, B. (2017). *Project-Based Learning: A Promising Approach to Improving Student Outcomes*. Issue Focus. MDRC. https://files.eric.ed.gov/fulltext/ED580907.pdf

Riegle-Crumb, C., Morton, K., Nguyen, U., & Dasgupta, N. (2019). Inquiry-Based Instruction in Science and Mathematics in Middle School Classrooms: Examining Its Association With Students' Attitudes by Gender and Race/Ethnicity. *SAGE Publications, 5*(3), 1-17.

doi: 10.1177/2332858419867653

Rock, M. (2004). Transfiguring it Out: Converting Disengaged Learners to Active Participants. *Teaching Exceptional Children,* 36(5), 64–72. https://doi.org/10.1177/004005990403600509

Rodriguez, A. J. (2015). What about a Dimension of Engagement, Equity, and Diversity Practices? A Critique of the Next Generation Science Standards. *Journal of Research in Science Teaching, 52*(7), 1031-1051. DOI 10.1002/tea.21232

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., . . . Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching, 46*(6), 632-654. doi:10.1002/tea.20311

Schwarz, C. V., & White, B. (2005). Metamodeling knowledge: Developing students' understanding of scientific modeling. *Cognition and Instruction*, *23*(2), 165–205.

Science. (2020). Retrieved October 24, 2020, https://education.mn.gov/MDE/dse/stds/sci/

Sherwood, C. (2020). "The Goals Remain Elusive": Using Drawings to Examine Shifts in Teachers' Mental Models Before and After an NGSS Professional Learning Experience. *Journal of Science Teacher Education, 31*(5), 578-600. doi:10.1080/1046560x.2020.1729479

Shevalier, R., & Mckenzie, B. A. (2012). Culturally Responsive Teaching as an Ethics- and Care-Based Approach to Urban Education. *Urban Education, 47*(6), 1086-1105. doi:10.1177/0042085912441483

Skinner, E. A., Kindermann, T. A., & Furrer, C. J. (2008). A Motivational Perspective on Engagement and Disaffection. *Educational and Psychological Measurement, 69*(3), 493-525. doi:10.1177/0013164408323233

Smart, J. B., & Marshall, J. C. (2013). Interactions Between Classroom Discourse, Teacher Questioning, and Student Cognitive Engagement in Middle School Science. *Journal of Science Teacher Education, 24*(2), 249-267. doi:10.1007/s10972-012-9297-9

Strachan, S. L. (2017). The Science Standards and Students of Color. *National Science Teacher,* 84(4), 47-50.

Sung, J. Y., & Oh, P. S. (2017). Sixth Grade Students' Content-Specific Competencies and Challenges in Learning the Seasons Through Modeling. *Research in Science Education, 48*(4), 839-864. doi:10.1007/s11165-016-9589-8

Tas, Y. (2016). The contribution of perceived classroom learning environment and motivation to student engagement in science. *European Journal of Psychology of Education, 31*(4), 557-577. doi:10.1007/s10212-016-0303-z

Ummah, S. K., In'Am, A., & Azmi, R. D. (2019). Creating Manipulatives: Improving Students Creativity Through Project-Based Learning. *Journal on Mathematics Education*, *10*(1), 93–102. doi: 10.22342/jme.10.1.5093.93-102

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Cambridge, MA: Harvard University Press.

Ware, F. (2006). Warm Demander Pedagogy Culturally Responsive Teaching That Supports a Culture of Achievement for African American Students. *Urban Education,* 41(4), 427-456. doi: 10.1177/0042085906289710

Williams, D. R., Brule, H., Kelley, S. S., Skinner, E. A. (2018). Science in the Learning Gardens (SciLG): a study of student' motivation, achievement, and science identity in low-income middle schools. *International Journal of STEM Education,* 5(1), 1-14.

https://doi.org/10.1186/s40594-018-0104-9

Appendix A:

Acronyms Used Throughout (in alphabetical order)

AP - Advanced Placement

CEA - Classroom Embedded Assessments

CER - Claim, Evidence, Reasoning

CRT - Culturally Responsive Teaching

EL- English Language Learner

FOK - Funds of Knowledge

NGSS - Next Generation Science Standards

NRC - National Research Council

NSTA - National Science Teacher Association

PBL - Project (or Problem) Based Learning

SEP - Science and Engineering Practice

STEM - Science Technology Engineering and Mathematics

ZPD - Zone of Proximal Development