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Impact Of Environmentally Focused Chemistry On High School Student Engagement And Scientific Understanding

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IMPACT OF ENVIRONMENTALLY FOCUSED CHEMISTRY ON HIGH SCHOOL STUDENT ENGAGEMENT AND SCIENTIFIC UNDERSTANDING

by

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DEDICATION

To my family, friends, and colleagues for your continuous encouragement and support. Thank you to all of my professors and peers who have shared their wisdom and knowledge with me as I worked to attain my Master's Degree. Most importantly, thank you to Spencer for your overwhelming patience and support as I embarked on this journey. I could not have done it without you.

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Introduction

Introduction

This capstone aims to address the question, *How can high school science educators improve student engagement and scientific understanding through environmentally focused chemistry curriculum?* As an educator, I believe that the purpose of education is to provide all people with equal opportunities to develop themselves and a foundation for their future as caring, contributing members of society. With this purpose in mind, the goal of education should be to provide students with knowledge of their past and present world, as well as the opportunity to cultivate the skills needed to navigate the future. Unfortunately, it has been my experience in the secondary science classroom, that sometimes scientific knowledge and skills are separated by topic, or even grade level.

The multi-state Next Generation Science Standards (NGSS) and the 2019 Minnesota Department of Education Science Standards which are set to be fully implemented by the 2024-2025 school year emphasize the need for cohesive knowledge and skill acquisition. These science standards focus on three distinct and equally important dimensions to learning science: Crosscutting Concepts, Science and Engineering Practices, and Disciplinary Core Ideas (DCIs) (NGSS Lead States, 2013). Each of these dimensions are built upon students exploring connections between scientific domains, identifying systems for discovery, and engaging in practices that build, deepen, and apply their understanding. Due to the scope and depth of the new standards, the implementation process for the new standards has been very gradual. However, I believe that it is my responsibility as an educator to ensure that I am always advancing my ability to provide students with the skills needed to navigate their rapidly changing environment.

For the remainder of this chapter, I will review my personal experiences with learning the processes and connectedness of science, and how these experiences led me to my current role as a chemistry educator. I will also share how these experiences shaped my desire to research and create a curriculum that allows students to draw connections between the multiple domains of science, while deepening their understanding. Concluding this chapter, I will review my capstone goals and the remaining related chapters.

My Background

I did not begin my journey planning, or even expecting to end up as a chemistry teacher. In fact, I would venture to say that my experience is not the traditional journey of becoming a public school educator.

Growing up on a small hobby farm in northern Minnesota, I was one of twelve children, all of whom were homeschooled from preschool through high-school graduation by a very dedicated teacher - our mother. She was diligent in providing classes to 4 or 5 grades at a time to maximize her efforts, and often used the observable world as a tool for teaching. We learned about local animals and biomes by traveling to wolf and bear sanctuaries, discussed chemistry and geology by exploring caves and mining facilities, and applied various sustainable agricultural practices on our small farm to increase crop yields. As a teen, I distinctly remember conducting pH tests and mineral tests on our soil to determine how we could improve growing conditions. These experiences laid a foundation for scientific processes and reasoning that I still apply today.

During my high school years, I was also called upon to help my younger siblings as they tackled subjects I had already completed. These were the formative moments that fostered my desire to help others become lifelong learners. I enjoyed the challenge of breaking down concepts to help build their self-confidence, and helping them see the real-world possibilities and application of reading, writing, science, and math. An added component of our education included caring for our small farm's assortment of cows, horses, sheep, and chickens, with the occasional milk goat or flock of turkeys joining the fun. These farm animal interactions coupled with my family's passion for hunting, fishing, and exploring nature fueled my love for the environment from a young age.

After completing high school, I had decided I wanted to be an educator; however, I was not sure which grade level and which topic was the best way to meet this goal. To help me decide, I served as an AmeriCorps Promise Fellow for two years providing after school enrichment programs for underserved student populations in northern Minnesota. It was eye opening to see the variation in student resources and engagement levels across my two student sites. My students ranged from kindergarten to 10th grade, but I observed that any opportunity to get outside or connect to nature was met with equal levels of excitement. Student engagement thrived as we collected artifacts from nature for art projects, examined watershed characteristics using models, and discussed the long term effects of mining iron ore on the environment. I discovered my personal interest in the natural world led to multiple opportunities for deepening student understanding of the connectedness of the world around us. So, after my two years ended, I began my undergraduate journey at the University of Minnesota, Duluth in the Teaching Life Science program.

The city of Duluth and surrounding areas are beautiful and teeming with opportunities to get outside in nature. I spent time exploring the shores of Lake Superior and hiked many of the nearby waterfalls, lichen covered rock formations, and tree shaded trails as I simultaneously stretched my personal understanding of education and science. In the classroom, my self-confidence was challenged as I realized my technical science background was severely lacking in comparison to my peers. However, I quickly realized that my abilities to think critically, apply systems thinking and take ownership for my learning were often just as important as the technical knowledge required to succeed in upper level science courses.

Despite my love for the city and the university, after two years in Duluth, I made the financially driven decision to transfer to Minnesota State University, Mankato to complete my Teaching Life Science degree. I'm very grateful as the move exposed me to prairies and agricultural practices unlike those I had seen in the northern parts of Minnesota. My upper level courses on stream ecology, animal behavior and climate change opened my eyes to how I could help my future students understand the full scope of science and their ability to impact their environment, community, and home. I became particularly fascinated with the impact of agriculture on water resources as I trudged through rivers and ditches studying macroinvertebrate populations and water health. I also found the effects of climate change disturbing as I examined animal behavior due to rising temperatures and changing resource availability. My experiences in Mankato really solidified the importance of using the observable world as a way to engage students in science.

Professional Application

After graduating from Minnesota State University, Mankato in 2018, I was hired as a ninth grade physics, chemistry, and engineering teacher at a 9-12 high school located west of the Twin Cities with approximately 1,300 students. Although these course topics are not specifically in the realm of my life science degree, I was drawn to the opportunity to learn more about other aspects of science and challenge myself in new ways. I have again found that my emphasis on drawing connections between scientific concepts adds a layer of valuable understanding to my students' experience. My chemistry students have especially benefited from seeing the real world application and cross cutting concepts within science.

Unfortunately, at this time my district's current chemistry curriculum is very disjointed as it jumps between concepts with few opportunities for students to develop natural connections. Units move from topics such as the scientific method, then states of matter, followed by gas laws, then atoms and elements, with little cohesion and few opportunities for engaging students in real world cross analysis of topics. These unit topics follow the 2009 Minnesota Academic Standards in Science which has primary strands such as "Physical Science", and substrands such as; "The Practice of Science" and "Matter" (Minnesota Department of Education, 2019).

This disconnectedness between topics in the field of science will hopefully be addressed by the newer NGSS influenced 2019 Minnesota Academic Standards in Science. These standards emphasize the "important practices used by scientists and engineers, which all students should learn to use with increasing sophistication over their years in school" and "identifies key concepts, or themes, which connect knowledge from the various disciplines of science and engineering into a coherent scientific view of the world" (Minnesota Department of Education, 2019). The 2019 MN standards draft document also shares that these skills and themes will be embedded with core ideas from physical sciences, life sciences, and earth and space sciences across all grade levels. I am confident that the emphasis on skills over content will increase engagement and reduce some of my students' current complaints about having already learned material even though it was at a different level.

It is towards the goal of developing a coherent applicable scientific learning experience that I approach this capstone project. I am hopeful that I can develop an environmentally focused chemistry curriculum that will help students use their previous knowledge as a foundation for deeper application of physics and chemistry concepts. This curriculum will provide opportunities for students to apply scientific reasoning and emphasize skills rather than rote memorization of stand alone topics. As a bonus, this real life application may lead to greater confidence as students continue learning scientific concepts in their high school career and beyond. My upper level chemistry colleagues have specifically mentioned that many of their students have a hard time drawing connections and extending their learning to new situations. In fact, my school's entire science department is very supportive of my desire to redesign the chemistry curriculum as it has been an area of frustration for the past few years.

The opportunity to research and create an environmentally focused science curriculum is not one that I take lightly. In my current role, I have not yet had the opportunity to create a personally relevant curriculum for my students. Many of the courses I currently teach were developed using shared assessments in the years prior to my arrival in our science department Professional Learning Community (PLC). However, as state science standards change and better teaching practices are identified, our department has agreed that it is time to revise current course offerings. Even though the developed curriculum will have some regional influences, it is my hope that these resources may be utilized by other science teachers from across the state as we collectively transition to the 2019 Minnesota Science Standards

On a personal and professional level, I am also looking forward to this project because I want to always challenge myself to improve using research based practices. I completed my undergraduate degree in 2018, so I'm familiar with some current techniques such as inquiry-based learning and systems thinking. However, I still have much to learn about their nuances and possible applications. Through extensive research and development, I am anticipating that I will be able to find new ways to engage and motivate my students, while giving them the tools they need to be successful in and out of the science classroom.

Summary

Over the course of this chapter, my capstone project has been introduced with the following guiding question: *How can high school science educators improve student engagement and scientific understanding through environmentally focused chemistry curriculum?* A brief overview of the Next Generation Science Standards and 2019 Minnesota State Science Standards was also provided. Personal experiences with science, the environment, and my role in science education were reviewed. Finally, I shared how these experiences led me to my current role as a high school science teacher hoping to improve upon the scientific learning experience of my students.

Moving forward, Chapter Two provides a deeper review of the new Minnesota State Science Standards, and reflects on current research regarding the impact of environmentally focused education on student engagement and scientific understanding. This chapter also analyzes case studies of environmentally focused science courses using different non-traditional instructional methods. These case studies assist in determining which instructional methods best support identified learning goals when developing the curriculum for this project. Chapter Three focuses on the methods I used to develop the curriculum for this capstone and provides details regarding the implementation and application methods for the curriculum. Chapter Four reflects on the process of learning, writing, and researching this project. This chapter also discusses the major takeaways from this curriculum development project; including project implications, limitations, and future steps from the development journey.

CHAPTER TWO

Literature Review

Introduction

The literature presented in Chapter Two will discuss the following themes: traditional chemistry education methods and their strengths and shortcomings in meeting current and upcoming Minnesota State Science Standards, the potential role of environmental chemistry in meeting new state science standards, the impact of environmental chemistry on students, and lastly, an examination of various environmentally concentrated education methods to promote student engagement and understanding. These themes will provide a foundation for a 9th grade Physical Science course curriculum focused on developing students' understanding of chemistry through an environmental education lens. This curriculum will be focused around answering the following question: *How can high school science educators improve student engagement and scientific understanding through environmentally focused chemistry curriculum?*

Chemistry Education

By definition, chemistry is the study of substances and the transformations these substances undergo (Merriam-Webster, 2022). There are many different methods to approach the learning of chemistry, but traditional teaching methods tend to utilize individualized topic lectures and relevant labs as the primary avenues for students to learn (Overman, et al, 2014). With a few individual variations, a common chemistry course structure might include four key sections or units: elements with compounds and mixtures, the periodic table, chemical changes, and conservation of mass in chemical reactions (Ramsden, 1997). According to Tytler (2007), chemistry teaching traditionally focuses on communicating conceptual knowledge, and employs key and abstract concepts to interpret and explain standard problems. Additionally, the inclusion of context is mainly secondary to concepts, and the use of lab or applicative work is to primarily illustrate scientific principles and practices (Tytler, 2007).

Although these methods have been employed consistently for over four decades, there is increasing concern that these individualized concepts and instructional methods are not motivating students to continue to study chemistry at more advanced levels. Johnstone (2010) suggests that these approaches may not include an appropriate understanding of how students learn and may lead to students experiencing information overload. Johnstone (2010) continues to say that despite enthusiastic instructors and good chemistry practices, many methods still featured the following characteristics: “Concepts were introduced that were inappropriate for the students’ stage of learning. Ideas were clustered in indigestible bundles, and theoretical ideas were not linked to the reality of the students’ lives” (p. 22).

At this point, it is important to acknowledge that guidance for teaching methods often stems directly from state and national standards and subsequent professional development required or offered by districts (Lakshmanan, et al., 2011). To fully understand the perimeters of current chemistry and physical science education, it is crucial to develop an understanding of the current state and national science standards. Minnesota is currently in the process of changing between current and new state science standards, so an overview of both will be provided.

Current Minnesota Academic Standards in Science. Current Minnesota science standards were adopted in 2010 and fully implemented in the 2011-12 school year (Minnesota Department of Education, 2022). Standards are categorized by grade level and then strand. There are three strands, or categories of science: Life Science, Earth and Space Science, and Physical Science. Substrands, or topics within the strand, are also provided. These substrands are similar to a unit in curriculum and are aligned with a standard which describes the content to be understood by students at the end of the substrand. A numbered code is also assigned to each standard as a method for organization and to help readers easily find standards in the document. Finally, a benchmark is provided as a way to measure student understanding and gives examples for methods to teach students the information presented within the substrand and standard (see Figure 1).

Grade	Strand	Substrand	Standard "Understand that ..."	Code	Benchmark
9-12	2. Physical Science	1. Matter	1. The structure of the atom determines chemical properties of elements.	9.2.1.1.4	Explain that isotopes of an element have different numbers of neutrons and that some are unstable and emit particles and/or radiation. *For example*: Some rock formations and building materials emit radioactive radon gas. *Another example*: The predictable rate of decay of radioactive isotopes makes it possible to estimate the age of some materials, and makes them useful in some medical procedures.

Figure 1. Current Minnesota State Science Standards sample (Minnesota Department of Education, 2022)

New Minnesota Academic Standards in Science. As a comparison, the incoming Minnesota Standards in Science were drafted in 2019, approved in 2021, and set to be implemented by the 2024-2025 school year (Minnesota Department of Education, 2022). These standards are aligned with the national Next Generation Science Standards (NGSS) and emphasize Three Dimensions: Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas. These dimensions are the guiding principles which lead to the replacing of strands with skills rather than the categories of science as seen in previous standards. Some examples of these skills: “Exploring phenomena or engineering problems”, or “looking at data and empirical evidence to understand phenomena or solve problems” (Minnesota Department of Education, 2022). Substrands have also been replaced with student centered tasks such as “Asking questions and defining problems”, or “Planning and carrying out investigations” (Minnesota Department of Education, 2022). Standards are aligned with student centered tasks related to the substrand and benchmarks are provided. Another addition is a “Content Area” section which identifies either Life Science, Earth and Space Science, or Physical Science with some additional content specific categories for secondary science. As a final change from current standards, the new benchmarks are written to reflect the integration of the three dimensions with the wording of each benchmark including a practice, a core idea and a cross-cutting concept. As stated by the Minnesota Department of Education (2022), benchmarks include statements of emphasis and/or examples that will help, but do not limit curriculum and instruction (see Figure 2).

Grade	Strand	Substrand	Standard	Content Area	Benchmark
9-12 Chemistry	3 Developing possible explanations of phenomena or designing solutions to engineering problems	3.1 Developing and using models	3.1.1 Students will be able to develop, revise, and use models to represent the students' understanding of phenomena or systems as they develop questions, predictions and/or explanations, and communicate ideas to others.	Chem: Structure and Properties of Matter	9C.3.1.1.1 Use the periodic table as a model to predict the relative properties of elements based on the patterns of valence electrons. (P: 2, CC: 1, CI: PS1) *Emphasis is on properties that could be predicted from patterns may include reactivity of metals, types of bonds formed (ionic versus covalent), and numbers of bonds formed.*

Figure 2. New Minnesota State Science Standards draft sample (Minnesota Department of Education, 2022)

The implementation of new Minnesota State Science Standards has led to a need for an aligned curriculum which meets the outlined science goals. Traditional lecture and lab style science courses align well with current science standards due to their emphasis on individualized topics and ability to meet applicable student benchmarks, but they will not fulfill the new science goals which aim to promote an interactive and applicative approach (Minnesota Department of Education, 2022). It is more important than ever for educators to consider alternate curricula options that will prepare students in developing the scientific reasoning and critical thinking skills they need to succeed in a rapidly changing world.

Environmental Chemistry

One context-based learning option which may better fulfill the new Minnesota State Science Standards emphasis on students' developing cross dimensional scientific understanding would be to implement an environmental chemistry (EC) focused curriculum. A context-based chemistry approach is characterized by the "use of societal, technical, or scientific contexts as the starting point for developing chemical understanding, with the intent of making chemical content more relevant to students" (Overman, et al., 2014, p. 1873). As the term "environmental" chemistry implies, there is an emphasis on the connection between the environment and the chemical processes contained within the environment (Mandler, et al., 2012). This emphasis on analyzing and understanding processes is different from "green chemistry" which focuses specifically on reducing or eliminating toxic substances, as well as general pollution prevention (U.S. E.P.A., 2022). In fact, according to Baird and Cann (2012), environmental chemistry is far more complex and "deals with reactions, fates, movements and sources of chemicals in air, water and soil" (as cited in Ali & Khan, 2016, p. 329).

As human societies face major environmental problems such as global climate change, extinction of plants and animals, and serious pollution issues, Ali and Khan (2016) suggest that chemistry, specifically environmental chemistry, is essential to identify, understand and solve environmental challenges. Many of these major environmental problems are interconnected and are threats to ecosystems and human health around the world (Ali & Khan, 2016). From a broad educational perspective, the chemistry classroom is a natural location for developing informed students and improving future leaders' decision making skills (Mandler, et al., 2012). This aligns with the notion of "education through chemistry" (Holbrook & Rannikmae, 2007, p. 1347), which includes a shift "from learning chemistry as a body of knowledge to promoting the educational skills to be acquired through the subject of chemistry" (Holbrook, 2005, p. 4 as cited in Jegstad & Sinnes, 2015, p. 660).

Adding a further layer, it is proposed that adding an environmental lens to chemistry curriculum has the potential to meet the goal of enhancing student learning of chemistry content and the goal of serving as a source of environmental knowledge (Mandler et al. 2012). Towards these goals, Environmental Chemistry differs primarily from traditional chemistry courses by providing students with environmentally focused case studies or opportunities to analyze and apply scientific reasoning and problem solving (Robelia, et al., 2010). A simplistic example of an environmental chemistry focused curriculum could include an environmental situation or problem that is shared at the beginning of lecture to provide context for the chemistry content being presented (Robelia, et al., 2010). Deeper case studies and observed outcomes from traditional chemistry courses converted into courses with an environmental or alternate chemistry curriculum will be discussed further in this chapter.

Although there are some small differences, Education for Sustainable Development (ESD) would be the closest comparison for the methods and reasoning behind Environmental Chemistry. ESD is an approach to education that applies science to sustainable practices with the intent of helping students become engaged citizens who participate actively in society in order to shape a more sustainable future world (Garner, et al., 2015). Introduced in 2004 and reaffirmed in 2019, ESD is still identified as a key part of the United Nations Sustainable Development Goals (SDG) (UNESCO, 2022). Environmental Chemistry meets much of the criteria for ESD, with an additional ability to meet the new Minnesota State Science Standards for developing scientific literacy and equipping people to use scientific principles and processes to make personal decisions and to participate in discussions of scientific issues that affect society.

One challenge identified by Jegstad and Sinnes (2015) in the implementation of ESD is maintaining a balance between general ESD methods and specific chemistry concepts. ESD has the potential to overpower chemistry content if curriculum is too general, while curriculum that is too chemistry-oriented is at risk of reverting back to fact-based learning. To prevent this, Jegstad and Sinnes (2015) suggest that developed classroom curriculum should first be chemistry-based, then applied to environmental based issues. These principles will be important to consider when creating an Environmental Chemistry curriculum which fulfills the new Minnesota State Science standards and engages students in scientific principles.

Environmental Chemistry Impact on Students

The differences between traditional chemistry teaching methods and Environmental Chemistry instruction have now been identified, but the impact on students has not been fully analyzed. This theme will focus on adolescent developmental challenges experienced at the secondary level, as well as relevant case studies and student centered outcomes related to engagement and student understanding of scientific principles. Lastly, the long term impact of environmental chemistry on student beliefs about science and scientific learning will be discussed.

As educators, the first priority in developing or implementing curriculum should be to provide the most impactful learning experience for our students with a focus on evidence based resources. For secondary education, there are additional challenges due to developmental changes occurring in students. An example of this can be seen in 2015 surveys conducted among Swedish students in grades six, nine, and twelve, which demonstrated that interest in and concern about environmental and sustainability issues tends to decrease in adolescence with dips commonly occurring between ages 13-17 (Olsson & Gericke, 2016). This decrease in environmental concern also aligns with a decrease in intrinsic motivation between ages nine to seventeen to learn science subjects, specifically chemistry and physics, due to a perceived lack of connection to the content (Gottfried, et al., 2009).

Adolescents of the same age can also be seen beginning to lower their perceived competence in science, leading to a decrease in interest and desire to pursue science in the future (Wang, et al., 2016). This is thought to be due to changes in maturity of cognition and changing learning environments. Prior to these ages, students primarily remained in elementary classes with feedback almost exclusively stemming from peers and their classroom teacher. Young students who were once overly optimistic begin to temper their cognitive ability assessments during this life stage based on comparisons and social cues from teachers, parents, and peers (Wang, et al., 2016).

With so many important changes occurring during the ages of nine to seventeen, the importance of environmental education during these ages should not be understated. As an additional consideration, Kaplan and Kaplan (2002) contend that the adolescent dip in environmental concern stems from interactions between evolutionary and cultural factors. These factors are based on the three informational needs of humans: the need for building mental models, the need for effectiveness, and the need for meaningful actions. Kaplan and Kaplan (2009) then developed and proposed a theory called the *Reasonable Person Model (RPM)* designed around the connections between these needs. The RPM theory states the need for building mental models is about increasing an individual's ability to understand and seek information and to build confidence in the use of such mental models. The second need involves enhancing one's personal beliefs in their ability to create change. And lastly, the need for meaningful actions suggests that people should have the opportunity to engage with and do things that matter (Kaplan & Kaplan, 2009).

Research suggests that these needs may be strongest in adolescence, and that adolescents need to feel that they are involved in planning and decision making which impacts them. Therefore, whenever possible, it is crucial to personalize educational activities involving adolescents with activities not initiated by adults. Instead, planning and decision making for adolescents will benefit from high levels of adolescent initiation, responsibility, and participation (Kaplan & Kaplan, 2002).

In the high school chemistry classroom, the challenges for engaging, or reengaging, students in light of the developmental and social changes occurring during these ages are significantly high. The use of environmental chemistry and similar context based learning methods can be very effective in assisting with this challenge. Although conducted at the college level, one study by Robelia et al (2010) found positive results comparing a traditional introductory chemistry course and an identical chemistry course that added an environmental scenario to the beginning of each lecture to provide context for learners. The results of that minor change to an otherwise traditional chemistry course indicated that students in the treatment section may have developed more pro-environmental attitudes due to their participation in a class which focused on environmental issues (Robelia, et al., 2010).

Robelia et al (2010) also suggest that providing environmental context can improve students' perceptions about the relevance of chemistry to real-life situations. Environmental context in chemistry makes the chemistry content more related to the students' everyday lives and thus more appealing for them. It should be noted that although many students in context-based chemistry courses exhibit a greater understanding of concepts than students in traditional chemistry courses, some common assessments showed little difference in student displayed understanding (Saleh, 2009). While students in a context-based course may not always necessarily develop a deeper understanding of individual topics; their knowledge is not impaired in any significant way. In fact, King (2012) believes that because student motivation and attitude are enhanced compared to those in a traditional course, context-based courses should be prioritized even if content understanding is not necessarily improved.

At this point, it is also important to note that some assessments may not accurately assess students' true learning. In fact, one challenge experienced by students and staff in context based chemistry courses is that these chemistry courses tend to vary depending on the instructor since topics are more varied when taught using context (Faikhamta, 2012). Therefore, school districts that heavily rely on standardized tests can find it difficult to teach a context-based style course because individual instructors may not focus on key concepts in the same way. Faikhamta (2012) continues to suggest that context-based chemistry courses work best when teachers choose their individual forms of assessment, but cautions that this may lead to little uniformity between courses at various schools or with other teachers. This disconnect between knowledge of processes and memorization of individual topics is likely to be addressed by the new Minnesota State Science Standards which focus on “enabling people to use scientific principles and processes to make personal decisions and to participate in discussions of scientific issues that affect society (NRC, 1996)” (as cited in Minnesota Department of Education, 2019, para. 3).

Because the new science standards are focused more on students developing scientific skills, rather than simply memorizing individual facts, the role of context-based courses, such as an environmental chemistry course, should not be overlooked. Environmental chemistry specifically emphasizes student learning and study of multidimensional processes, which is very different from traditional chemistry courses which often provide direct instruction on separated topics. These opportunities for multidimensional studies may also allow students to perform better on soon to be updated Minnesota standardized tests (Minnesota Department of Education, MCA, 2022), which may in turn increase student beliefs regarding scientific proficiency and abilities based on their feedback from standardized tests (Marsh, et al., 2005).

As mentioned previously, students tend to form more positive attitudes towards chemistry after participating in a context-based course. However, as one final consideration, student feelings are also influenced by the instructor and the quality of the course. For example, in one case study conducted by Gutwill-Wise (2001), some participants shared negative feedback regarding a traditional turned context-based undergraduate chemistry class, but the negativity seemed to be influenced by the dispassionate attitudes of their graduate level student instructors. In that same case study, students initially shared frustration with errors in the curriculum material; however, student attitude data saw a significant improvement when taught a more refined version of the course the next year. Because of this study, it is recommended that high-quality course materials and proper facilitator training are implemented to promote positive student feelings towards context-based learning experiences.

To summarize the main components of this theme, adolescents between the ages of 13 to 17 experience the greatest decrease in environmental behaviors and scientific motivation. These factors are compounded by developmental changes and the need for students to feel that they are involved in planning and decision making that is relevant to them. This decrease could be reduced by implementing context-based environmentally focused science courses as students in these courses tend to experience greater pro-environmental attitudes, increased perception of chemistry relevance in everyday living, and improved attitudes and motivation toward science.

Effective Instruction Methods and Resources for Environmental Chemistry

There are many research based instructional methods which can promote the student skills required by upcoming science standards. To better understand the scope and opportunities of an environmental chemistry focus, it is important to review case studies and observed outcomes from traditional chemistry courses which were converted into courses with an environmental or alternate chemistry curriculum. This final section will provide a brief overview of several methods and how they have been, or can be applied in general science or environmental chemistry specific environments. Examined methods will include: inquiry-based learning, problem-based learning (PBL), systems thinking, Culturally Sustaining Pedagogy (CSP), modeling, and phenomenon-based learning. Method overviews will also weigh the limitations of each method to provide some context for which methods may best support a variety of student learners.

Inquiry-Based Learning (IBL). Inquiry-based learning is the practice of teaching and learning through asking questions and encouraging student-led discovery of answers through scientific processes (Gasterland, 2021). Founded in progressive education, inquiry-based learning practices aim to improve learning outcomes by providing students the opportunity to actively facilitate their own learning. There are two primary methods of inquiry-based learning; teacher directed inquiry and student directed inquiry (Smithenry, 2010). Both methods, but specifically teacher directed inquiry, share many characteristics with problem-based learning (PBL), which we will discuss next in this section.

An example of student-led inquiry based learning in a chemistry setting can be seen in a sustainable paints case study (Blatti, et al., 2019). This study guided students in discovering natural materials to use for making paints, developing protocols to formulate paints using chemistry components, and designing experiments to test the resultant paint properties. According to Blatti, et al. (2019), this open-ended, inquiry-based exercise allowed the students to “feel free in an educational setting, with no judgment of their ideas and positive encouragement as they iteratively ‘fail’ and improve their procedures, experiments, and methods of collecting data” (p. 2856).

Limiting factors to this instructional method include the implementation time required by instructors as students work through the process of discovery. Additionally, educators who implement this method must have a strong sense of the research process and how scientists solve problems. These skills are needed in order to properly model discovery and guide students through the scientific processes they explore (Gasterland, 2021).

Problem-Based Learning (PBL). This is a style of student-centered learning which facilitates the integration of multiple subjects into an investigation where students first identify problems and related factors in a given situation or scenario, then learn more in order to provide possible solutions (Jansson, et al., 2015). This method can share some overlap with inquiry based learning as sometimes teachers will provide the scenario and students will work together to solve the problem or find the answers.

One example of PBL was implemented in a master’s level Environmental Chemistry course to investigate if PBL could be a more successful instructional method for teaching environmental chemistry than the traditional teacher-led education model (Jansson, et al., 2015). At the beginning of this study, students were introduced to the concept of student-centered learning and PBL to provide guidance on expectations and methods. Throughout the course, PBL scenarios were presented using a single page document containing short descriptive text and an image intended to raise thoughts regarding key issues in the field, such as the handling and environmental impact of toxic chemicals. An important part of the process as identified by Jansson, et al. (2015), is that the associated expected learning outcomes of the current scenario were also listed at the top of the page with the intent of reinforcing the learning process. The responsibility then is placed on the students and their PBL group to identify, gather, and analyze additional information related to the PBL scenario, based on guidance provided by the instructor and applicable learning outcomes. The results collected from the first two years of the course strongly suggest most participants were impressed with the modifications and found PBL to be an efficient technique for both learning, and acquiring a deeper understanding of environmental chemistry (Jansson et al., 2015).

One critique of PBL is that the minimally guided instructional approach used in PBL is not as efficient or effective when compared with guided instructional approaches used in other traditional teacher-focused approaches (Kirschner, et al., 2006). This concern is especially compounded in courses where instructors are not well versed in the method, as well as in courses where student understanding of learning expectations are not developed. Special consideration should be given to student maturity and experience with this method before implementation.

Systems Thinking. This method of education emphasizes reactions and processes in the context of broader applications, which aims to apply chemistry disciplinary knowledge towards a more holistic understanding of the field (Blatti, et al., 2019). Already often used in conjunction with Problem-Based Learning (PBL), Blatti et al.

(2019) suggest that using systems thinking to combine chemistry education and environmental education has the potential to address fundamental socio-ecological challenges. These identified challenges include climate change, contamination by microplastics, food scarcity, and loss of biodiversity, and further illustrate the connectedness between science and the world.

An example of systems thinking in action can be seen in the topic of climate change. Climate science is complex and crosscutting, and making sense of climate change requires systematic analysis which pulls concepts from chemistry, biology, and physics, along with environmental, atmospheric, and earth sciences (Mahaffy, et al., 2017). The complexity of life systems such as our climate makes them difficult to understand because they are composed of multiple connected levels that interact in dynamic ways. However, implementing systems thinking in the science classroom allows students the unique opportunity to see the interconnectedness between different scientific disciplines and relate ideas from various courses as they apply the scientific process (Mahaffy, et al., 2017).

As with inquiry based learning and PBL, a limitation to the wider acceptance and application of systems learning is the concern that important scientific content might be left out when introducing topics through multidimensional real world contexts rather than individualized topic lessons (Mahaffy, et al., 2017). Another concern is the overwhelming of students with the number of factors influencing a scenario. Students new to systems thinking must be intentionally guided through the direct relationships identified to build confidence in concepts.

Culturally Sustaining Pedagogy (CSP). Paris and Alim (2017) describe culturally sustaining pedagogy (CSP) as a practice that "positions dynamic cultural dexterity as a necessary good, and sees the outcome of learning as additive rather than subtractive, as remaining whole rather than framed as broken, as critically enriching strengths rather than replacing deficits" (p. 1). Introduced by Gloria Ladson-Billings, culturally sustaining pedagogy is the focus on a student's cultural background and implementing inclusivity in order to attain academic success, cultural competency, and the awareness and ability to impact the status quo (Ladson-Billings, 1995, p. 160). Incorporating culture into a curriculum allows students the opportunity to engage and reflect on cultures outside of their own culture.

One example of culturally sustaining pedagogy practices in an introductory chemistry classroom can be seen in a two-week study of the Flint, Michigan water crisis which was developed for high school and undergraduate students (Yu & Linden, 2022). In the first week of the exercise, students learned the chemistry of lead contamination while reviewing previously learned course concepts. In the second week, the students participated in discussions focused on the environmental and social injustices experienced by the people of Flint, MI. Collected student feedback from this study was very positive with many participants sharing that they felt engaged with chemistry beyond the classroom. Many students also expressed an appreciation for the real-life application and the inclusion of a cultural connection (Yu & Linden, 2022).

CSP can be applied in any classroom setting, but can be particularly beneficial when applied in contexts where underrepresented students are not often included (Paris & Alim, 2017). However, one challenge with the implementation of CSP is the oversimplification of cultural factors and use of culture as a hook to gain students attention (Paris & Alim, 2017). It is crucial for educators to critically examine their individual pedagogical approaches to identify and remove the continuation of historical inaccuracies, harmful stereotypes, and veil of good intentions.

Modeling. "Developing and using models" is specifically identified in the new Minnesota Science Standards under Strand 3, Substrand 1 (Minnesota Department of Education, 2022). Standard 1 further expands this guidance: "Students will be able to develop, revise, and use models to represent the students' understanding of phenomena or systems as they develop questions, predictions and/or explanations, and communicate ideas to others" (Minnesota Department of Education, 2022, paragraph 16). A scientific model usually represents a system and could be shown as a physical replica, visual diagram, analogy, or a computer simulation (NGSS Lead States, 2013).

An example of modeling in chemistry classrooms can occur when students learn to create, evaluate, and modify particle-level models based on data and observations they collect from simple experiments (Posthuma-Adams, 2014). Commonly students practice communicating their ideas through class discussions and informal whiteboard presentations. With an environmental lens, opportunities to discuss the relationship between temperature, volume and pressure as seen occurring in roadways during winter or summer months could lead to deepening student understanding of conceptual ideas and concrete evidence (Posthuma-Adams, 2014).

One concern with modeling can be seen in oversimplifying the atmosphere into a condensed model. Although this simplification might make it easier to understand what is happening, students may not consider the multiple inputs and outputs impacting the condition of the atmosphere. So, one concern is that students need to understand that models have limitations and there are factors we can not control or identify until further research has been conducted.

Phenomenon-based learning. This method of learning was pioneered in Finland and occurs when students are presented with unique or commonplace phenomena and undergo a process of discovery to understand the processes involved. Wang and Liu (2022) suggest phenomenon-based learning is most effective when the 5E instructional model is implemented. The 5 E's are: engage, explore, explain, elaborate, and evaluate. The 5E model was developed on the basis of the constructivist approach to learning, in which learners build new ideas based on prior knowledge and understanding.

According to Wang and Liu (2022), the engagement phase captures students' interest by allowing them to experience or witness a scientific phenomenon or a problem to be solved. Next, the exploration phase encourages student discourse about the phenomenon through questioning, investigation, and observations. The explanation phase allows instructors to facilitate discussions and students to refine their reasoning of what they have discovered. The elaboration phase asks students to apply what they have learned in different but similar situations. The instructor can also use the elaboration phase to guide students toward the next learning concept. The evaluation phase allows for student reflection and teachers opportunities to evaluate student learning.

Interestingly enough, phenomenon-based learning and modeling are identified along a continuum, rather than two completely different methods. Grusche (2019) encourages educators to help students move from exploratory to more theory focused experiments, from inductive to deductive reasoning, and from their everyday world to the world of science. The critiques of phenomenon-based learning are similar to inquiry-based learning and problem-based learning which include the concern that students will not fully understand the depth of individual topics presented due to the multiple variables presented. Additionally, due to the newness of this method, there are currently very few teacher resources and training opportunities developed around phenomenon-based learning, so many teachers employ the methods incorrectly or with a limited view of the possible applications.

Although there are distinct differences, each of the methods discussed in this section share a common focus: the goal of improving student learning and engagement. Whether systems-thinking, culturally sustaining, or phenomenon-based, each instructional method focuses on helping students develop deeper multidimensional critical thinking skills and leaves behind traditional methods of teaching which reinforce passive learning. No longer is the emphasis on students learning individual abstract concepts and focusing on memorization. Any of these identified methods have the potential to be employed in an environmentally focused chemistry classroom depending on instructor level of comfort and knowledge of the method.

Summary

The implementation of new Minnesota State Science Standards which emphasize multidimensional learning require a new approach to teaching chemistry concepts. As the world faces devastating environmental challenges, such as global climate change, and serious pollution issues, the chemistry classroom is a natural location for developing informed students and improving future leaders' decision making skills especially in regards to the environment (Mandler, et al, 2012). Combining chemistry and an environmental focus can help students develop relationships across sciences, while also yielding other benefits for students. This is especially important in the secondary classroom as student motivation to learn science subjects typically decreases between the ages of nine to seventeen, due to a perceived lack of connection to the content (Gottfried, et al., 2009). However, studies have shown that simply adding environmental context can improve students' perception regarding the relevance of chemistry to real-life problems, while also making learning chemistry more attractive (Robelia, et al., 2010).

This review of the literature also identified several instructional methods by which an environmental lens could be applied to a chemistry course. The primary conclusion is that in addition to being an important field of science, environmental chemistry is also an effective means of teaching and learning chemistry by providing context to chemistry content. This research will provide a foundation for a 9th grade Physical Science course curriculum focused on developing students' understanding of chemistry through an environmental education lens. This curriculum will try to answer the following question: *How can high school science educators improve student engagement and scientific understanding through environmentally focused chemistry curriculum?*

The upcoming chapter will include an overview of the developed environmental chemistry focused curriculum, the intended audience, and an explanation of theories and standards used in developing the curriculum. A short discussion of the timeline required to complete the project will also be included, as well as how the effectiveness of the curriculum will be evaluated within the unit and high school science department.

CHAPTER THREE

Project Description

Introduction

The purpose of this capstone project is to enhance the learning experience of students in the high school chemistry classroom. Research supported instructional methods were utilized to develop a cohesive ten-day long physical science unit curriculum. This curriculum focuses on developing students' understanding of chemistry by implementing an environmental lens. Towards this goal, the developed curriculum aims to answer the following question: *How can high school science educators improve student engagement and scientific understanding through environmentally focused chemistry curriculum?*

This chapter will begin by sharing researcher positionality, then outlines the curriculum design framework used and steps taken to complete an engaging and relevant chemistry unit curriculum for high school students. The developed unit emphasizes students exploring chemistry concepts using environmentally focused phenomenon based learning and problem-based learning methods. This unit of study was created using the Understanding by Design (UbD) framework which will be explained in this chapter as well.

Positionality

It is important to note my own experiences with the environment will be different than many of my students and colleagues. I am a white, middle-class female in my twenties who grew up in a predominantly white town in northern Minnesota. Aside from some time spent teaching abroad in Costa Rica and several road trips around the United States, I have lived in Minnesota my entire life. When approaching the topic of environmental education in chemistry courses, I realize my biases towards the state's continental climate which features all four seasons ranging from cold, often frigid winters to hot, humid summers.

My environmental lens has also been shaped by my experiences as an able-bodied person who had nearly unlimited access to the outdoors growing up. I acknowledge that not every student or person I encounter has the same life experiences and perspectives regarding nature and natural resources. Additionally, because I was homeschooled through high school graduation and never experienced a "traditional classroom education", I also realize that I view learning differently than others in my field. These experiences are important to consider because when creating the environmentally focused curriculum for this capstone project, I need to be able to articulate and identify my reasoning for including specific resources and methods over other similarly effective options.

Guiding Principles

Rationale for this unit and unit structure came about because of the literature review in Chapter Two. Research showed that many students feel disconnected from the relevance of chemistry in their daily lives and that many traditional chemistry teaching methods unintentionally reinforce separation between scientific concepts (Johnstone, 2010). However, the addition of an environmental lens to chemistry curriculum has shown a positive increase in student perception about the relevance of chemistry to real-life problems (Robelia, et al., 2010). Other benefits of environmental chemistry include improvements in student engagement and student learning, and an increase in students' environmental knowledge (Mandler et al., 2012).

Environmental chemistry is a natural bridge between chemistry concepts and the environment as it is the study of the sources, reactions, transportation, effects, and fates of chemicals across air, soil, and water environments. The use of phenomenon based learning and problem-based learning aligns well with environmental chemistry as these methods empower students to utilize multidimensional analysis when faced with real-world situations. Phenomenon based learning occurs when students are presented with unique or commonplace phenomena and encouraged to undergo the process of discovery to understand the processes involved (Grusche, 2019). Phenomenon based learning has been shown to be especially effective when the 5E model is implemented with students (Wang & Liu, 2022). The five phases of the 5E model are: Engage, Explore, Explain, Elaborate, and Evaluate.

Problem-based learning occurs when students identify problems and related factors in a given situation or scenario, then learn more in order to provide possible solutions (Jansson, et al., 2015). Research has shown problem-based learning can be difficult if students are unfamiliar with the method, but can be highly effective when students are provided with instructor support and clearly communicated learning outcomes (Jansson, et al., 2015). Both of these instructional methods have unique benefits and challenges to implementation, however the goal is to employ these methods with an environmental focus to help create a more indepth and relevant science learning experience for students.

To guide the curriculum development process, principles of backwards design were implemented from Understanding by Design (Wiggins & McTighe, 2011). The Understanding by Design framework prompts teachers to begin with the end in mind. The first step is to identify the desired results, then identify evidence of learning, and finally design the instructional plan (Wiggins & McTighe, 2011). The desired results of this project were to see increased student engagement and improved scientific understanding. Acceptable evidence of these results will be collected using a pre- and post-assessment measuring student connection to content and understanding of multidimensional scientific processes. The instructional components work towards meeting Minnesota State Science Standards for 9-12 Chemistry by including research supported instructional methods such as phenomenon based learning and problem-based learning.

It is my belief that the guiding components of Environmental Chemistry and the described Understanding by Design process have allowed me to develop a curriculum that improves student engagement and depth of scientific understanding, while also connecting them more deeply to the environment.

Project Description

For this capstone project, I created a ten-day environmentally focused chemistry curriculum using phenomenon based learning and problem-based learning methods. The curriculum was designed for implementation in all 9th grade physical science classrooms at a high school in Minnesota. This curriculum will not cover an entire semester and is intended to be integrated within an already existing chemistry curriculum.

The created curriculum addresses the following 9-12 Chemistry Minnesota State Science Standards (see Figure 3). However, because this is only a ten-day unit, I recommend instructors plan for students to engage with these standards and practices in other lessons during the course.

Grade	Strand	Substrand	Standard	Content Area	Benchmark
9-12 Chemistry	2 Looking at data and empirical evidence to understand phenomena or solve problems	2.1 Analyzing and interpreting data	2.1.1 Students will be able to represent observations and data in order to recognize patterns in the data, the meaning of those patterns, and possible relationships between variables.	Chemistry - PS: Matter and Its Interactions	9C.2.1.1.1 Analyze patterns in air or water quality data to make claims about the causes and severity of a problem and the necessity to remediate or to recommend a treatment process. (P: 4, CC :2, CI: PS1)
9-12 Chemistry	3 Developing possible explanations of phenomena or designing solutions to engineering problems	3.2 Constructing explanations and designing solutions	3.2.1 Students will be able to apply scientific principles and empirical evidence (primary or secondary) to explain the causes of phenomena or identify weaknesses in explanations developed by the students or others.	Chemistry - PS: Matter and Its Interactions	9C.3.2.1.3 Construct an explanation for the phenomenon of solution creation and identify from patterns how the properties of the resulting solution depend on the interactions between solute and solvent or on concentrations of solutes. (P: 6, CC: 1, CI: PS1)
9-12 Chemistry	4 Communicating reasons, arguments and ideas to others	4.2 Obtaining, evaluating and communicating information	4.2.2 Students will be able to gather information about and communicate the methods that are used by various cultures, especially those of Minnesota American Indian Tribes and communities, to develop explanations of phenomena and design solutions to problems.	Chemistry - PS: Matter and Its Interactions	9C.4.2.2.1 Communicate and evaluate claims by various stakeholders, including Minnesota American Indian Tribes and communities and other cultures, about the environmental impacts of various chemical processes on natural resources. (P: 8, CC: 2, CI: PS1)

Figure 3. Prioritized grade 9-12 Chemistry Minnesota State Science Standards (Minnesota Department of Education, 2022)

Using water and water quality as a reference, this unit encourages students to explore properties of matter, types of matter, and mixture separation techniques. Students will examine cultural and environmental impacts of chemical processes, and practice the Claim, Evidence, Reasoning (CER) method. The unit concludes with students performing authentic scientific data collection to provide environmental context for chemistry concepts.

The completed unit plan is presented as a physical and digital binder with all resources organized together (Appendices A-D). Organizing the resources together in this way supports easy sharing with others. The unit assessment is provided first as this was the first item developed using Understanding by Design (UbD) principles (Appendix A). Next, an overview of the unit is included with the essential questions and major activities that will be conducted each day, a blank lesson template to help teachers understand the structure of each lesson, and detailed teacher plans which outline the order of learning and student activities throughout the unit (Appendix B).

The last section of the binder includes any materials that the teacher may need, including activity resources, keys, and worksheets (Appendix C). The teacher resources in Appendix C vary from completed powerpoints and lab sheets to basic topic outlines. These resources aim to cover the key chemistry and environmental concepts, while still supporting the individuality of teachers and their preferred method of direct teaching. The final section provides any student materials such as lab sheets and assignment information (Appendix D). These worksheets can be printed as is, or modified to be digital depending on student and teacher needs.

Audience/Setting

This curriculum was written with a 9th grade physical science classroom in mind. This high school is located in Minnesota and has approximately 1,300 students in attendance. The high school student population is 90% white students, with the remaining student population consisting of students of color. Hispanic students comprise the next highest racial group at 5%. There are 66 adults in teaching positions along with multiple paraeducators, special education paraprofessionals, instructional paraprofessionals, and one-on-one paraprofessionals. 4.2% of students receive free and reduced lunch during this school year, which is down from 10.2% in 2019. This high school also features a strong Special Olympics Minnesota Unified Sports community. The Unified Sports initiative emphasizes inclusive movement programs leading to the creation of new friendships, and builds a positive environment by welcoming all people regardless of their ability or disability.

Timeline

The first three chapters of this capstone project were drafted between late January and May 2022. I began the final portion of the capstone course and started writing the curriculum in June 2022. The first part of June was spent researching and deciding which chemistry topics I would focus the curriculum on. By late June, I began writing unit objectives and a rough unit outline. July was spent completing the unit outline and writing individual lesson plans. These lesson plans include student based objectives, materials and applicable student assessments, as well as instructions for implementing environmentally focused chemistry lessons into a classroom. It was during this time that I also narrowed my focus from two broad environmental units to one environmental unit with more detail.

During the months of July and August, I focused on updating Chapter Three with relevant details, drafting Chapter Four, and completing final lesson plans. The associated project presentation and final artifact paper was completed in August 2022. I anticipate the developed curriculum will be integrated into the 9th grade chemistry classroom in the 2022-2023 school year with modifications and improvements occurring throughout the school year.

Assessment

For this ten-day unit, students will be assessed using an initial chemistry pre-test and post-test which will measure their ability to apply multidimensional scientific reasoning and principles to different scenarios. The pre-test and post-test will also attempt to measure student interest in and level of engagement with science concepts. The pre-test is optional if time is a limiting factor. The individual lesson plans also feature several informal checks for student understanding, including 3, 2, 1 exit tickets and structured labs with targeted learning objectives.

The formal assessments and informal checks for understanding are designed to provide students and course instructors with feedback on the level of student understanding. These assessments were developed using principles from Understanding by Design (UbD) from Wiggins and McTighe (2011) which promotes starting with identifying desired results, determining acceptable evidence, and planning learning experiences. This assessment met the second step of UbD and was created prior to any curriculum being developed.

Summary

This chapter focused on the details and guiding principles for this curriculum design project, intended audience, as well as the general timeline used to complete the capstone. The curriculum's intended audience are 9th grade chemistry students at any Minnesota high school. The resources created for this project can be used in other chemistry classrooms across the state as they meet Minnesota State Science Standards for 9-12 Chemistry.

Chapter Four will summarize the findings from the research question: *How can high school science educators improve student engagement and scientific understanding through environmentally focused chemistry curriculum?* It will provide personal and professional reflection of the curriculum design process, as well as discuss the key resources used to develop the curriculum. Chapter Four will also identify limitations, implications and discuss future projects and questions.

CHAPTER FOUR

Reflection

Introduction

The primary goal of this project was to design an environmentally focused chemistry curriculum that improves the high school student learning experience and answers the guiding question: *How can high school science educators improve student engagement and scientific understanding through environmentally focused chemistry curriculum?* This project was developed in response to updated Minnesota State Science standards and the need for a more cohesive 9th grade chemistry curriculum at a high school in Minnesota.

In this chapter I will discuss what I have learned throughout the process of creating a capstone. I will refer back to the literature review and the key resources used in writing the curriculum. Next, I will discuss the limitations and implications of my project, as well as identify future research projects and questions. The final section will also examine the impact of this project on the education profession and future students. These components will provide a reflection on the learning process and explain how this project fits into my life and the larger academic community.

Personal Reflection

During this capstone process, I have learned a lot about myself and how I approach learning. In Chapter One, I appreciated the opportunity to reflect and write about my experiences in the environment, as those life experiences were ones I had never compiled on paper before. In Chapter Two, I found myself getting lost in the literature and avidly reading article after article as I learned more about methods to help my students learn and get excited about science. My own spark for learning was ignited the more I engaged with the material. This chapter reminded me of the importance of building student confidence and allowing them to guide their learning. This chapter also challenged my writing and research skills as I attempted to concisely communicate the key learnings from a research based view. In Chapter Three, I was able to practice my newfound knowledge and skills by developing an environmentally focused chemistry curriculum. This was a huge learning experience as I struggled at some points to ensure the curriculum was not too specific to my personal teaching style and found myself editing back the amount of detail to allow for individual teacher flexibility.

Now, in Chapter Four, as I reflect on the process, I realize that I feel more confident than ever in researching and writing research based curriculum to support my students' learning. As mentioned in Chapter One, I have been teaching science courses for just over three years and have never had the opportunity to create a curriculum to support students. Having a predetermined curriculum has been a blessing in some regards, but I also enjoyed the challenge and opportunity to practice my own curriculum writing skills.

Writing the Curriculum

While creating this curriculum project, several resources and findings in the literature review were especially helpful. These resources included: the definition for environmental chemistry and the case studies for phenomenon based learning and problem-based learning. Multiple times, I found myself reading the definitions and examples of the instructional methods to ensure I was meeting the key steps for implementation.

In the literature review it was found that phenomenon based learning is highly effective when it follows the 5E instructional model (Wang & Liu, 2022). The 5 phases of the 5E model are: Engage, Explore, Explain, Elaborate, and Evaluate. These five phases helped me form the basis for how the unit was structured and how lessons within the unit were created. Each individual lesson within the unit begins with something engaging. For example, an interesting question posed to get the students started thinking, such as "What makes water good or bad?" or a video showing an unusual phenomenon in action. Each lesson continues to allow students to follow the 5 E's to completion.

One unexpected struggle I faced when implementing this method was that 70 minutes was not always enough time to complete all 5 phases in a deep and meaningful way. To combat this, some assignments were shortened or assigned as homework to allow for students to complete the evaluate phase individually. Research conducted by Wang and Liu (2022) on the 5E model in a chemistry course was also very helpful in providing an example of how to teach chemistry concepts through a climate change focused environmental lens.

Because learning through phenomena and problem-based scenarios may be new to a majority of the students, most of the activities in the newly created unit are structured. An example of this can be seen when students are provided with an article explaining the different perspectives and controversy surrounding a mining ban in the Boundary Waters Canoe Area. Students are initially provided with prompts to discuss in groups. These discussions are then followed by a teacher-led discussion and presentation about the possible methods of separating mixtures and cleaning water. This decision was made after reading Kirschner, et al. (2006) which found that student maturity and their experience with student-led methods greatly impacted their ability to effectively lead their own learning. Kirschner, et al. (2006) suggested that until learners have sufficiently high prior knowledge to provide "internal" guidance, teachers need to provide strategic external guidance to aid their learning.

Another important resource was Jansson, et al. (2015), which advocated that prior to implementing the problem-based learning method, students are introduced to the concept of student-centered learning and problem-based learning to provide guidance on expectations and methods. This led me to build an introduction to problem-based learning into the unit curriculum. Jansson, et al. (2015) also advised listing associated expected learning outcomes of any problem-based scenario at the top of the page to assist in reinforcing the learning process. An example of this can be seen in the student handout for the Algal Blooms: Chemistry and Prevention problem (Appendix D) which shows the key learning outcomes listed at the top of the document. Example: *Students will be able to make a claim, identify evidence, and provide reasoning about the causes and severity of a problem based on data.* These clearly identified learning outcomes can assist students in self assessing their learning.

Project Limitations

The curriculum created for this project is only one single environmentally focused unit out of an entire school year. Although an environmental focus can improve the student chemistry learning experience, a ten day unit is not enough time for students to be fully comfortable and experienced with the true process and nuances of phenomenon based learning and problem-based learning. This is the largest limitation of the curriculum when it stands on its own. Until further phenomenon based learning and problem-based learning curriculum are developed, students may not learn all the tools and skills necessary for truly effective learning using these methods.

Another limitation is that this curriculum is best implemented in regions where water is not frozen at the time of implementation. Because the problem based portion of the unit relies upon students to collect water for testing, ideally there should be open water available for them to access. Frozen water from lakes, streams or rivers may impact their final data and influence their experience if instructors do not address and plan for that aspect of the unit

A final limitation to this curriculum is that it has yet to be tested in an actual class. All developed curriculum and lessons should be tested, then modified for student understanding and engagement based on the results. This curriculum will be no exception. Until the curriculum has been tested, I cannot know with certainty whether it effectively increases student engagement and scientific understanding. Additionally, when implementing this unit, the instructor may find that certain topics need to be covered again in a new way or that extra practice is needed for students to truly understand specific concepts or ideas.

Implications

Mandler, et al. (2012) advocated that from a broad educational perspective, the chemistry classroom is a natural location for developing informed students and improving future leaders' decision making skills. Because physical science is currently a required high school course, all students could theoretically experience increased engagement, deeper scientific understanding, and improved decision making skills if they are exposed to instructional methods highlighted in this capstone project. This unit curriculum assists in this student goal by providing a curricular starting point for teachers new to phenomenon based learning or problem-based learning. This capstone also provides several examples of instructional methods and condensed case studies which teachers can utilize to incorporate an environmental lens in their classroom.

As schools implement the new Minnesota State Science Standards, and more states adopt the Next Generation Science Standards (NGSS), teaching through phenomenon based and problem-based methods will become more applicable to meet state standards. Especially since the new standards focus more on the process of learning as opposed to the individual concepts. Implementing or sharing this capstone curriculum can provide schools with a starting point to move away from mainly content oriented learning. Educational governing bodies and schools can see the advantages to students becoming proficient in the learning process and will likely require teachers to implement teaching styles which emphasize the process of learning over content.

Future Work and Questions

Developing this curriculum was only one of my first steps toward incorporating more phenomenon based learning methods into my classroom. Looking ahead, I will be implementing this curriculum in my classroom this fall, as well as sharing the unit with my colleagues who teach the same ninth grade introductory chemistry course. I will use their feedback and my experiences to revise and modify as needed. I also have plans to write two environmentally focused chemistry units about soil and air which will discuss the unique characteristics and environmental aspects of those states of matter.

In the future, more work could also be done to include citizen science projects in environmentally focused chemistry curriculum. Projects like Earth Echo Water Challenge or CoCoRaHS (Community Collaborative Rain, Hail, and Snow) Network would allow students opportunities to extend their learning beyond the classroom walls. Students would benefit from seeing the real world application of their data collection, particularly when used to support a healthy environment. Including citizen science components in environmentally focused chemistry curriculum could naturally encourage students to contribute to the greater science community as lifelong learners.

Lastly, some questions that kept coming to mind throughout this process were: What are effective ways to support teachers new to environmentally focused courses? How can they be supported in creating and implementing phenomenon based learning and problem-based learning methods in their classroom? Are there tools and resources that could help a teacher make this transition easier? Moving forward, I will be advocating for additional phenomenon based learning educator courses for our science department as we transition to the new MN Science Standards. Having a unified format to courses will hopefully allow students to focus on engaging more deeply with science content and concepts rather than switching between learning methods.

Summary

This capstone project has worked to answer the question: *How can high school science educators improve student engagement and scientific understanding through environmentally focused chemistry curriculum?* This chapter focused on reflecting on the learning process during which I identified that I enjoyed researching new instructional methods and the curriculum development process. I shared the primary literature resources I used in developing environmentally focused chemistry curriculum, specifically the phenomenon based learning and problem-based learning resources.

Another component of this chapter was examining limitations and implications of this project. Lastly, I discussed future research opportunities related to environmentally focused chemistry, the impact on students and the educational profession, as well as questions that arose throughout the process.

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