IN SEARCH OF THREE-DIMENSIONAL LEARNING: USING SELF-STUDY TO CHANGE A SECONDARY BIOLOGY TEACHER'S PRACTICE

BY

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DISSERTATION

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ABSTRACT

The purpose of this research project was to provide a model for traditional teachers who want to change their practice using self-study research when professional development is unavailable. Issues and tensions that arise when transitioning from a traditionally taught secondary biology unit to a unit that is more in alignment with the Next Generation Science Standards (NGSS) are explored. Data collection included using field notes, critical friend's conversations and feedback, video and audio recordings, Educators Evaluating the Quality of Instructional Products (EQuIP) rubric unit evaluations, self-study personal history and class portrait, concept maps, tag clouds, and student work. Data analysis compared the changes in practice that occurred between the enactment of a traditionally taught secondary biology unit, and an instructional unit developed by Project NEURON at the University of Illinois. Changes in teacher understanding of the NGSS, classroom dynamics, curricular alignment with the NGSS, and three-dimensional learning are discussed. The self-study concludes that teacher change can occur using in-depth, critical reflections on practice. Traditional teachers who want to transition to the NGSS and three-dimensional instruction can benefit from the findings of this study. Tensions and issues surrounding science education reforms can give valuable insights to science educators in anticipation of the transition to the NGSS.

Keywords: Self-study, Next Generation Science Standards (NGSS), Project NEURON, EQuIP Rubric

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CHAPTER 1 - INTRODUCTION

This study employs a self-study research methodology to uncover changes in my pedagogy that occur during the implementation of a secondary biology unit based on the three dimensions of the Next Generation Science Standards (NGSS Lead States, 2013). The use of eight core science and engineering practices are one of the cornerstones of the Next Generation Science Standards (NGSS). These practices are the foundation for Phenomenon-Based Learning (PhenoBL) and Modeling Instruction (MI), both of which are research-based science education pedagogies (Haag & Megowan, 2015; Maltese, 2016) that integrate the conceptual framework for science education as suggested by the National Research Council (2012).

In chapter one, first, the presentation of the study overview, and the definition of terms are presented. Next, a background of the problem is presented, followed by a statement of the problem. Finally, a discussion of the purpose and significance of the study along with the specific research question takes place.

Chapter two is a discussion of the relevant research that guides this self-study. First, a history of science education reforms in the United States is discussed, followed by a discussion of literature that emphasizes the importance of STEM education. In the next section, a review of literature self-study research and changes in a teacher's attitudes, beliefs, and knowledge occurs. Finally, chapter two concludes with a presentation of the theoretical framework for this self-study.

Chapter three gives a description of the research study methodology. First, a presentation of the study's timeline along with a description of both the study's setting and participants occurs. A description is made of the data sources, measures, collection, and analysis methods. Next, is an exploration of issues of study rigor, reliability, and validity, along with ethical issues that may arise because of the study. Finally, the limitations of the study along with challenges and study assumptions are addressed.

Chapter 4 is a presentation of the study's findings that result from the data that is collected and analyzed during the three phases of the self-study.

Chapter 5 is an exploration and discussion of the research findings, conclusion, and call for further research and recommendations.

The Appendices will provide a reference place for documentation that is referred to throughout the study.

Definition of Key Terms

Action Research is a cyclical process is used by a single teacher or a group of teachers to problem solve educational issues using a repetitive seven-step process (Pine, 2008). Action research "embraces a variety of research methodologies including case studies, descriptive studies, survey studies, interview studies, observational studies, phenomenological studies, quantitative studies including quasi-experimental designs, and historical research " (p. 67).

Best Practices are research-based educational practices, methods, or techniques that consistently show results that are that improved over other methods ("Best practice," 2014).

Educators Evaluating the Quality of Instructional Practices (EQuIP) Rubric for science lessons and units provides educators with the criteria necessary to measure the overall quality and alignment of units to the Next Generation Science Standards (NGSS Lead States, 2013).

Modeling Instruction (MI) is a research-based pedagogy that integrates a model-centered curriculum with a student-centered teaching method in science education (Haag & Megowan, 2015).

Phenomenon-Based Learning (PhenoBL). Phenomena are observable events that students can use the three dimensions to explain or make sense of (NGSS Lead States, 2013). In phenomenon-based learning, “a classroom observes a real-life scenario or phenomenon — such as a current event or situation present in the student’s world — and analyzes it through an interdisciplinary approach” (Zhukov, 2015, para. 1).

Self-study is a research methodology that allows educators to push the boundaries of teaching, and to reform their professional identities through the testing and modeling of effective self-reflection (Hicks, Samaras, & Berger, 2004).

The Three Dimensions of the National Research Council’s *Framework* combine science and engineering practices, crosscutting concepts, and disciplinary core ideas to form each standard (National Research Council (U.S.). Committee on a Conceptual Framework for New K-12 Science Education Standards., 2012).

Background of the Problem

There is a long history of efforts to reform science education in the United States. The science standards reform movement began in 1983 with the publication of *A Nation at Risk (National Commission on Excellence in Education, 1983)* and its assertion that schools in the United States were failing. The reform efforts continued to evolve with Project 2061’s *Science for All Americans* (American Association for the Advancement of Science, 1989). Project 2061 presents the argument that all students should achieve scientific literacy in order to help them lead socially responsible and personally fulfilling lives, and that students should develop the skills to think independently and critically to understand how the world works. In subsequent years, through discussions about proposed reforms, and due to frustrations about the lack of effective reforms, science education reformers realized that specifics detailing reform-based instruction and learning would need to be developed (Bianchini & Kelly, 2003; DeBoer, 1991). These initiatives were presented by reformers first as “benchmarks” in *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993), and then as “standards” in *The National Science Education Standards* (National Research Council, 1996).

Enacting science education reforms in the United States is a complex process. Public education in the United States is under the control of the states rather than the Federal Government. Policies for local funding, teacher certification, choosing appropriate curricular materials, and determining suitable student learning assessment tools, are also under the control of the state. As a result, national reform efforts to develop standards-based curriculum and instruction (American Association for the Advancement of Science, 1993; National Research Council, 1996) are interpreted and carried out by the individual states and then be implemented in the district, the local school, and classroom levels. This complex process can result in challenges for teachers attempting to translate science standards into their practice (Bianchini & Kelly, 2003).

It was at the time of these reforms in the 1990’s that inquiry-based learning was being promoted. One of the main ideas in the *National Science Education Standards* (1996) was its attempt to translate science standards into practice through the emphasis on inquiry as an educational goal for science teachers (Hunter, 2014). A decade later, the *Biological Science Curriculum Study* (BSCS) released a report which outlined the 5E instructional model. This instructional model provided science teachers with the pedagogical direction that allowed them to creatively stimulate student learning through inquiry (Bybee et al., 2006).

More recently, in the *Framework for K-12 Science Education* (National Research Council (U.S.). Committee on a Conceptual Framework for New K-12 Science Education Standards., 2012), and *The Next Generation Science Standards* (NGSS Lead States, 2013), the reform focus has shifted to promoting student learning through the development of science reasoning through science practices. The three dimensions of the *Framework;* science practices, crosscutting concepts, and core ideas, form the basis for each performance expectation.

Statement of the Problem

With the continuing call of science education reformers to shift science teaching away from the memorization of facts, teacher-led lectures, and cookbook labs, the NGSS will allow students to plan and carry out their investigations through student-centered strategies (Felder & Brent, 1996; Huff, 2016; Krajcik & Merritt, 2012; National Academy of Sciences, 2015). However, the desire to move science learning away from the memorization of facts is not novel. In fact, *Science for All Americans* suggested this change in pedagogy in 1989 (American Association for the Advancement of Science). So why is there such resistance among science educators to shift from a learning approach that is teacher centered to one that is student centered? While the reasons are multifaceted, much blame can be placed on teacher training at both the University and professional development levels (Haag & Megowan, 2015).

The National Science Teachers Association (NSTA) estimates that there are nearly two million private and public K-12 science teachers in the United States (2016a). While this number seems high in comparison to the nation’s 3.6 million teachers, NSTA considers the country’s 1.6 million elementary teachers to be teachers of science. The NGSS currently has 26 lead state partners which comprise approximately half of the United States’ science teaching force. In 2011-12, about 56% of all teachers in the United States were over 40 years old (National Center for Education Statistics, 2016), meaning that most of the nation’s teachers are years removed from contemporary university teacher education programs that focus on "best practices" in science classrooms.

The National Academy of Sciences' recent report on the state of science teaching in the United States (2015) came to the conclusion that very few teachers have the necessary experience with the science practices outlined in the NGSS. For example, one of these practices, modeling instruction (MI), has been found to have an influence in how prepared teachers are to implement NGSS in their classrooms (Haag & Megowan, 2015). A recent study revealed that high school teachers who had completed an average of 90 hours of professional development (PD) in modeling instruction were significantly better prepared, and were more motivated to implement NGSS in their classrooms than traditional teachers. Teachers trained in modeling instruction found that it is well aligned to the practices and skills that outlined in the NGSS and researchers estimate that there are about 7,000 teachers who have currently been trained in modeling instruction nationwide (2015). While there are a significant number of teachers who have had adequate training, a lack of proper training leaves most science teachers in the United States unprepared for NGSS implementation in their classrooms.

There are currently multiple publishers of science materials, developers, and individuals who assert that their instructional materials align with the NGSS, but experts have found that many of these instructional materials do not properly align with the three-dimensions of the NGSS (Krajcik, 2014). The problem is that the process of designing materials that have crosscutting concepts, disciplinary core ideas, and science practices that blend and allow students to design solutions and make sense of phenomena is a tough process, especially when students are asked to become proficient in a bundled set of performance expectations (2014). Fortunately, there has been a recent release of some content specific bundled standards.

Efforts to make the curriculum development process for NGSS aligned units clearer have recently been published on nextgenscience.org (2016) in the form of “bundled” standards. Bundles are created by arranging groups of standards together to create a unit of instruction endpoints. Bundling is helpful in the standard implementation process as it allows students to see better how concepts are connected to streamline instructional time (2016). Twelve-course modules were released in the summer of 2016, but only for Kindergarten, first and fourth grades at the elementary level, and one course at the middle school level. At the high school level, two bundles were released; one domains model for chemistry, and one for physics, but the biology conceptual progression and domains bundled model have not yet been released. Almost three years after the State of Illinois adopted the NGSS as its state science standards, resources for creating instructional materials that are designed for use with the NGSS have still not become available for many grade levels and secondary science disciplines.

A report by the National Academy of Science (2015) on the state of science teaching in the United States came to some new sobering conclusions. The report found that there is a need to close the gap that exists between current instruction methods, and the new way of teaching science, which will need to be attended to on an individual basis with teachers. Little attention has been given to the systematic support of science teachers’ learning, including an understanding of disciplinary core ideas, science practices, and crosscutting concepts outlined in the Framework (2012).

The final draft of the Next Generation Science Standards was published on April 9, 2013. While the lead states are committed to adopting the standards, which some have already done, there is a lack of firm implementation timelines and strategies (Haag & Megowan, 2015). This hesitation has also been felt in the educational community. Some teachers readily embrace educational innovations with great enthusiasm, while others discard innovations when they become frustrated after a few attempts (Abrami, Poulsen, & Chambers, 2004; Lam, Cheng, & Choy, 2010). Part of this teacher frustration in embracing new educational innovations lies in the traditional way many science teachers teach science, and due to a lack of professional development in the NGSS. Researchers understand the connection between the successful implementation of the NGSS and professional development. One author describes how the Next Generation Science Standards "have the potential of transforming science education if work is done to inform and prepare the teachers who will be expected to implement these standards" (Blanton, 2012, p. 259).

One of the greatest concerns about implementing NGSS at all levels is that many of the current models of teaching in schools continue to be lecture and fact based which is incompatible with satisfying the mandates of the NGSS (Cooper, 2013). Thus, there is an urgency nationwide to identify the most effective types of professional development which will be needed for teachers to be better prepared to face the challenges of the NGSS. The National Science Teachers' Association (NSTA) has identified conceptual shifts that are needed to implement the NGSS. The NSTA understands that significant changes are required in the structure of science courses and currently existing curriculum sequences, and the NSTA contends that experienced teachers must make significant shifts in both the way they teach and in course content (National Science Teachers Association, 2013). Another area of concern in the implementation of the NGSS is a lack of curricular materials that align to the three dimensions of the NGSS.

On the NGSS EQuIP rubric release page, it is stated that "while curriculum and instruction will need to shift with the adoption of the NGSS, there is currently a lack of high-quality, NGSS-aligned materials" (NGSS Lead States, 2013, para. 2). Some teachers and administrators are unsure about NGSS launching successfully. In a recent survey of about 5,000 K-12 Science, Math, Technology, and Engineering (STEM) supervisors and teachers, about 80% of those who completed the survey were familiar with the NGSS (Heitin, 2014). The same survey also revealed that only 60% of respondents held a favorable view of the reform, and 6% of respondents had a negative opinion of the NGSS. Yet even with the potential that the NGSS has to reform science classrooms in the United States, the same survey found that only 10% of respondents planned on purchasing new, high-quality instructional materials that align with the NGSS standards and instruction, and most teachers said they would continue to use their existing curriculum with just minor enhancements.

There is a gap in the knowledge of what a well-designed secondary biology NGSS instructional unit that integrates disciplinary core ideas, science and engineering practices, and crosscutting concepts will look like in practice. While work is currently being done by publishing companies to develop secondary biology instructional materials that align to NGSS (Allan, 2014; Sampson et al., 2014; Sampson & Schleigh, 2013; Shields, 2006; Thornburg, 2013), some of these instructional materials fail to show a consistent integration of the three dimensions, as well as a haphazard inclusion of inquiry-based activities. A lack of well-designed curricular materials could be a major roadblock to successfully reforming science education in the coming years, and teachers may resort to using instructional materials that do not successfully integrate the three dimensions of science education. Additionally, while instructors understand that science practices are paramount to student learning, very few instructors consistently use this method. Fortunately, a local university has a curriculum development center which has prepared units that more closely align with the NGSS. A professionally developed Project NEURON unit is used in this study ("Novel education for understanding research on neuroscience," 2016).

Purpose and Significance of the Study

As a secondary science teacher with over two decades of experience, I was excited to learn about the adoption of the NGSS by the State of Illinois when it was introduced several years ago during a science department meeting. The NGSS, we were told, would bring a major shift in both science content and a new way to teach science. This announcement of yet another curricular “change” elicited a variety of comments from teachers in our science department. Some of the veteran teachers complained that the NGSS was just another of the many educational incentives that show up and then quickly disappear after a few years. The younger teachers were excited about the NGSS as they had recently been exposed to the “new way to teach science” in their respective university teacher education programs. Most teachers in our science department are considered “veteran” teachers, with over three-quarters of our science teachers having taught in public schools for more than ten years. Several of the novice teachers in our department, who were recent college graduates, regularly use a student-centered pedagogy based on inquiry learning, while most of the veteran teachers in our department, including myself, teach on the traditional side of the spectrum. Traditional teaching methods are often “rote,” and are characterized by surface learning that often results in students just replicating the material (McParland, Nobel, & Livingston, 2004). With my identity as a science teacher on the traditional end of the spectrum being long established, I found myself in conflict both with the pedagogical ideas of the younger teachers and with the three-dimensions of science education as is suggested by the NGSS. Because of these tensions, I asked myself, “How could I change my practice to better align with the NGSS without professional development for the betterment of my students?"

The purpose of this research study is to attempt to change my teaching practice to better align with the three dimensions of the NGSS, which will, in turn, allow my students to learn three-dimensionally. Analysis of the result of this research project will help fill the gap in knowledge of how secondary science educators who teach more traditionally, such as myself, can use a self-study methodology to change their practice to more closely align with the three-dimensions of the NGSS. Other science teachers who are transitioning to the NGSS may be able to gain insight into the conceptual change that results in an educator who is transitioning from teaching science traditionally into a unit that aligns with the three dimensions of NGSS. They will also become aware of many of the tensions and issues that I face undergoing this self-study. This knowledge will also provide a written account of my transitional experiences and tensions in this research project to help other educators gain insights into the type of NGSS professional development that is needed in their schools, and to help give them a better understanding of the NGSS “best practices.” Another goal of this research project will be to help other secondary biology teachers gain a better view of what implementing an NGSS unit may look like in their own classrooms.

Primary Research Question

The primary research question in this study is:

> What issues arise when using self-study to guide my transition from teaching traditionally to teaching a unit that aligns with the three-dimensions of the NGSS?

Chapter 1 Summary

In Chapter 1, first, the study overview and the definition of terms was presented. Next, a background of the problem was described followed by a statement of the problem. Finally, the purpose and significance of the study were discussed, and the guiding research question in this study was introduced.

In Chapter 2, I will present a discussion of the relevant literature that guides this self-study. A history of science education reforms in the United States will be submitted, which will be followed by a review of literature which highlights the importance of STEM education. Next, literature concerning teacher change will be used as an introduction to the theoretical framework and theoretical underpinnings of the self-study.

CHAPTER 2 – LITERATURE REVIEW

The purpose of this self-study is to change my practice through the implementation of a systematic, cyclical research methodology. A model unit that more closely aligns with the Next Generation Science Standards (2013) and the Framework (2012) will be employed, and data will be collected to analyze the tensions and issues that I experience while transitioning from a more traditional teaching pedagogy to student-centered instruction that better align with the NGSS. This research study will be conducted in three phases. Phase I will occur before the enactment of the study and will include a self-analysis of my teaching style while presenting science content traditionally. Also during this phase, I will discuss efforts that I made to develop an NGSS aligned instructional unit, the DNA and cell division unit, and I will evaluate the unit using the Educators Evaluating the Quality of Instructional Products (EQuIP) rubric for NGSS alignment (NGSS Lead States, 2013). A professionally developed Project NEURON unit will be selected that more closely aligns with the NGSS for enactment in my classroom ("Novel education for understanding research on neuroscience," 2016). Phase II will occur during the enactment of the study and will include data collection and analysis while I am teaching the Project NEURON unit. Phase III will occur after the adoption of the study, and using the experience that I gained while writing the DNA and cell division unit, modifications to the Project NEURON unit will be suggested to incorporate additional components that may help the unit to better align to the NGSS. The overall research question that guides this self-study is: What issues arise when using self-study to guide my transition from teaching traditionally to teaching a unit that better aligns with the three dimensions of the NGSS?

It will be necessary to review current literature to establish the cognitive and theoretical origins of the research to lay the groundwork for this self-study. The literature review is arranged in five sections. In the first section, a history of science education reforms in the United States is presented which highlights key reform efforts that culminate in the NGSS. The second section discusses the current state of K-12 science, technology, engineering, and mathematics (STEM) education in the United States. In the third section, literature on teacher change is discussed. In section four, the theoretical framework of the study is presented in subsections on action research, self-study teacher research, personal history self-study, and reflective teaching. Finally, in the fifth section, literature on the theoretical underpinnings of the study is explored, including active learning, modeling instruction, constructivism and social constructivism, and conceptual change theory.

A History of Science Education Reforms in the United States

To view this research study through the lens of the Next Generation Science Standards, a historical overview of the science education reforms that have occurred in the United States leading up to its implementation will help clarify the call for a new science education reform. This historical review will also contribute to framing the shift that the NGSS suggests from more traditional science teaching methods seen in American schools in the past, to new instructional methods that integrate the three dimensions of the NGSS into science instruction.

The final version of the NGSS was released on April 9, 2013, by several national groups and a consortium of 26 states. These new standards are based on contributions of The Committee on a Conceptual Framework for New K-12 Science Education Standards, and published in *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (2012), and with contributions from prior science education reforms. However, while these new standards offer an unprecedented promise to reform science education, the call for reforming science education has occurred many times in the United States over the past two hundred years.

In this next section, an analysis of how science education reforms have influenced biology education will be made to address the following questions. First, how have the different waves of science education reforms in the United States influenced the curriculum that is taught and the instructional methods that are used in secondary biology classrooms over time? What contributions have these previous reforms had on the development of the Next Generation Science Standards? Will any patterns emerge through a survey of science education reforms that have occurred, and if so, what will they reveal, and how do these patterns contribute to the development of the Next Generation Science Standards? How do secondary science educators view this latest reform? A review of literature will investigate past science education reforms in the United States to help in analyzing their impact on secondary biology education from Colonial America to the present day. It is hoped that patterns found in science education reforms of the past can provide insight into the future of science education in the United States.

Biology Education in Early America: Colonial to the Late Nineteenth Century

Before the 1750's in Colonial America, education was agrarian in nature as parents taught their children the farming skills they would need to survive in the New World. In New England, the Puritans believed that everyone should be able to read the Bible, so their children were taught reading and basic mathematics in their homes (Lutz, 2014). While some affluent families sent their sons back to England for schooling, private grammar schools began to open in New England to prepare their sons for Ivy League Colleges. In the Southern States, rich plantation owners would hire private teachers to educate their young. In 1751, the introduction of private American academies in Philadelphia for religious instruction became more commonplace (Towbridge, Bybee, & Carlson-Powell, 2004). Males from affluent families with practical interests took utilitarian courses in botany, natural philosophy (physics), astronomy, physical geography, surveying, navigation, and agriculture. Biology taught as a unified subject would not appear until the early 1900's. For most average children, what they learned about the natural "biological" world in colonial America was from interacting with nature each day to survive through subsistence farming. It was against the law for children of slaves to receive a formal education (Lutz, 2014).

During the American Revolution, strong beliefs in public education were argued by founding fathers such as Thomas Jefferson, who believed that one necessary component of democracy was education, yet there were strong voices of opposition to the involvement of the Federal Government in public education (Lutz, 2014). For those who were not from elite families in the late 1700's and early 1800's, the education they received bore little relation to the education that they needed (Adams, 2009). A secondary school in the early 1800's for most students was dominated by the study of classical languages such as Latin and Greek in an educational system that had been handed down from the Middle Ages (DeBoer, 1991). Those fortunate enough to have a classical education often became members of the clergy or used their educational status to bolster their standing in society.

Modernization of the classical educational system was a dynamic process that occurred during the middle to late 1800's. During this period in the United States, the science topics that were taught in school were shaped by the Industrial Revolution. The shift to an industrial and technical society from an agrarian society began transforming science education (Towbridge et al., 2004). A substantial migration of people to urban areas occurred during the Industrial Revolution, in conjunction with many thousands of people immigrating to the United States, resulted in increasing numbers of students taking secondary science courses. Equally important, in 1837 the Secretary of Education in Massachusetts, Horace Mann, began a reform initiative with the goal of ensuring that each citizen becomes educated and virtuous voters by creating common standards, establishing grade levels, and requiring mandatory attendance (Lutz, 2014). In like manner, by the 1870's many other states duplicated Horace Mann's educational system, and all states had scattered locally controlled tax-supported schools, yet compulsory school attendance would not be complete in the United States until Mississippi finally passed a mandatory education law in 1918 (Towbridge et al., 2004).

The decline of the classical education system led to the continual inclusion of sciences into secondary school curriculum. It was during this time that a shift occurred towards self-discovery and independent inquiry in science education (DeBoer, 1991). Interestingly, during this era, one research study found that by 1840, the curricular subjects of astronomy, natural philosophy, and chemistry were much more prevalent in private educational institutions for upper and middle-class girls than in similar institutions for boys (Tolley, 1996). The same study revealed that in secondary schools in North Carolina and Virginia between 1800-1840, 35% of girls' schools advertised courses in botany, while only 2% of boys' schools offered botany. Additionally, in Pennsylvanian schools in between 1830-1889, 77% of girls' schools offered botany, while only 33% of boys' schools offered the same course. The study also found that the curricular focus for secondary male students during this period was concentrated on classical studies, while girls' curricular focus was more science-centered (1996).

During the colonial era and through most of the 1800's, biology was not yet a course of study. Courses such as botany and natural philosophy would not become part of a unified biology curriculum until early in the twentieth century. Science courses during this era were book-taught, where students were required to memorize and recite texts as the primary mode of instruction.

Science Education Reform in the Late 19th Century - The Committee of Ten: 1870's-1890's

Another result of the Industrial Revolution with the massive influx of people from rural areas and immigrants into American cities in the late 1800's, was the domination of colleges and universities over secondary science courses through college admission requirements. For instance, in 1872, Harvard University began requiring physics for admission (Towbridge et al., 2004). Furthermore, high school science textbooks were abridged versions of college textbooks. The introduction of "labs" also occurred during this era, which were usually stereotyped and dull activities (2004). In 1890, only 6.7% of 14-17 year old's' attended secondary school, yet the classical studies curriculum was overwhelmed with a new list of subjects such as the physical sciences, U.S. history, and English literature (DeBoer, 1991). Some organization was needed to guide college-bound students, of which there were few, into the rigorous college admission process. Resentment developed between secondary school personnel and higher education in the 1890's because of a vast number of courses that had to be offered to students to gain admission into college. At the same time, pressures were building because of the majority of students who were non-college bound and desired more practical and applied courses (1991).

As a result of these pressures, in 1892 the National Education Organization (NEA) created a committee to determine which courses would be taught in high schools so that students attending different high schools would be similarly prepared for college (Sheppard & Robbins, 2007). The president of Harvard at that time, Charles A. Eliot, chaired the committee, and nine subcommittees were formed to sort out questions such as: How long should each course be allowed? What was the best pedagogy for each subject? What courses should be taught in high school? And finally, should course sequences be different for students who attended college as compared to those who did not? During the late 1800's, grade placements of the different biology based courses were chaotic, and as a course of study, biology did not yet exist. The natural history subcommittee decided that each student should study one year of either zoology or botany, and recommended that physiology be taken later in high school (DeBoer, 1991). Furthermore, the subcommittee decided against unifying all three courses into a unified biology course at that time. Many on the subcommittee argued that botany was the most valuable biological course and that biological topics be taught after the physical sciences of chemistry and physics (Sheppard & Robbins, 2007). Zoology was considered less of a popular course because students had less of an aversion to plants, which were deemed more attractive than the preserved animals dissected in a zoology class (DeBoer, 1991).

Even though the recommendations that the Committee of Ten made were suggested and not required, they did have a substantial impact on American secondary science education, mostly as it was the first organized American science education reform effort. At that time, high schools were small, and they found it difficult to staff all the natural history courses. In a study of its effectiveness, 10 years after the committee's recommendations were made, it was found that only 12% of schools offered a one-year course in either zoology or botany, and a general biology course had still not been developed (Sheppard & Robbins, 2007). During the 1890's, the common educational pedagogical method was through "mental discipline," where each subject taught in high school was valued per how well the mind as a muscle could be exercised because of studying the subject. Additionally, it was at this same time that laboratory-based instruction became increasingly popular. While some educational leaders advocated for a heuristic, inquiry-based approach to lab-based science, the most common model for labs was a strict procedural confirmation of phenomena through a dull, stereotyped pedagogy. For example, students in botany and zoology classes were expected to make detailed observations of a multitude of animals and plants. They were then required to memorize intricate descriptions of their anatomical features and create detailed drawings of what they observed (DeBoer, 1991).

Science Education Reorganization and Reform: 1900-1920

The years after the Committee of Ten's reform recommendations were made saw several decades of science education reform efforts. In 1901, the College Entrance Examination Board was formed which was a joint effort between college professors and high school teachers, and it was charged with the implementation of the Committee of Ten's recommendations (DeBoer, 1991; Sheppard & Robbins, 2007). One result of the new college admission requirements were subject specific standard achievement exams. The unforeseen consequence of the exams was to make factual content knowledge the most beneficial aspect of learning to measure, which is still causing tensions between pedagogy, curricula, and educational policy in modern times. The College Entrance Examination Board issued its first biology "exam" in 1913 (Sheppard & Robbins, 2007). Consequently, the results of these efforts did make college entrance requirements more flexible. During this time, even though high school enrollments doubled each decade between 1890 and 1930 , in 1900 only 10.2% of eligible 14-17-year-old students were attending high school, and most of those students did not graduate (Digest of Education Statistics, 1981).

It was during the time between 1900 and the early 1920's that the mental discipline of learning philosophy was criticized and rejected. In its place came a call for a curriculum that had a social relevance that met the social demands of a society that was in transition, and of an educational system that was not keeping up with these changes (DeBoer, 1991). In 1913, a

Commission of the National Education Association (NEA) met, called the Commission on the Reorganization of Secondary Education, to once again broaden college admission requirements by investigating high school subject matter. Several reports were issued that demanded curricular changes occur in secondary education. For the first time, differences in student mental capacities were address, as well as the "application of knowledge to the activities of life, rather than primarily in terms of the demands of and subject as logically organized science" (National Education Association, 1918, p. 18).

It was also during the first years of the 20th century that biology as a unified course was finally developed. There were several contributing factors to the eventual integration of biology as a unified course of study. First, the development of a single, year-long course that incorporated botany and zoology made scheduling much easier for high school and college admission requirements (Sheppard & Robbins, 2007). Additionally, a well-accepted hierarchy of high school science courses emerged with general science being taught in 9th grade, biology in 10th grade, and physics and chemistry being taught in grades 11 and 12 (Towbridge et al., 2004). The newly developed biology course became so popular between the years of 1900 to 1930 that its popularity exceeded the enrollments of both physics and chemistry combined (Sheppard & Robbins, 2003). Another contribution to biology's success was the increasing number of students enrolled in high school that were required to take biology. Changes in child labor laws, a continuing shift in demographics from rural to urban educational environments, and continued immigration waves, all impacted increasing biology course enrollments (Rosen, 1959). As a consequence of the biology courses' success, courses in zoology and botany nearly disappeared in the 1930's (Sheppard & Robbins, 2003).

Medical Education in the United States

Biology education in early American history is closely intertwined with medical training in the United States. Students have traditionally studied biology as a precursor to medical school. Therefore historical similarities are shared between medical education as an advanced form of biological research. During the colonial period until the end of the 19th century, medical education followed the apprenticeship model present during that era which included the transmission of various rituals, practices, and beliefs from the doctor to his apprentice over a period of months to years (Hodges, 2005). The formal medical education that is familiar today was only available to a small group of elites in Austria, Germany, France, and the United Kingdom, who were taught in the medieval universities. Physicians who emerged from the European system commonly practiced only in the very rich elite class. In the United States, those practicing medicine during colonial times were mostly men who were informally trained as barber-surgeons, the clergy, midwives, apothecaries, and bone-setters, who were from the relatively inadequately educated lower and middle classes (2005). The first professorship in the practice and theory of medicine was created at the College of Philadelphia in 1765, and Yale created a medical department in 1810 (Flexner, 1910).

While a detailed history of medical education exists in Europe during the 18th and 19th centuries, the historical record in the United States during that time reveals a gap, mostly because few authors or doctors were interested in recording it (Bonner, 1995). Thus, it was not until modern writers attempted to describe medical education during the colonial period that any history exists at all, and its accuracy is questionable. For example, in the book *Medicine in the American Colonies* (Beck, 1966), first published in 1850, a somewhat romanticized view of American doctors was portrayed. Doctors were portrayed as heroes who would ride their horses through the night to treat their patients. Between the years 1810 and 1840, twenty-six new medical schools were started in the United States, with the addition of forty-seven more medical schools which opened between 1840 and 1876 (Flexner, 1910). Training at the newly established American medical schools was didactic, and clinical training was rare.

During the late 19th and early 20th centuries, the rise of medical schools in university settings led to the development of courses such as immunology, biochemistry, and pharmacology (Hodges, 2005). These courses coincided with advances in biology such as sterile technique and anesthesia. Even with these scientific advances, medical schools were very selective and discriminatory about whom they admitted: mostly white, Christian men. The admissions discrimination was so profound that women attempted to open their medical schools, which ultimately failed due to the fact that they women were offered fewer science classes throughout their education (Witz, 1992). It was thought at the time that highly educated women would become arrogant and would not be able to “take their proper place in the social order” (1992, p. 208).

The rise of the laboratory would have profound effects on biological and medical advances in the early 20th century. In the mid-1800’s, the only laboratory that was available to physicians was the pharmacy, but by the early 1900’s, a host of additional laboratory types emerged including; public health, microbiological, forensic, and pharmaceutical (Berger, 1999). The rise of the laboratory for medical studies corresponds to the increase of laboratory experiences available to secondary and higher education students at the time, and laboratories evolved into an “obligatory passage point for researchers who want to make new discoveries” (1999, p. 1). As new advances in medicine occurred throughout the 20th century, discoveries trickled down to scientific learning in higher education, which eventually had an impact on biology content in secondary schools.

Science Education Reform in The Progressive Era: 1920's – 1950's

Although ideas about progressive education were developing in the late 1800's, and had begun to influence educational institutions in the early 1900's, the publication of *The Cardinal Principles of Secondary Education* in 1918, by the Commission of the Reorganization of Secondary Education, was an affirmation for those with progressive ideas that they were on the right track (DeBoer, 1991; Wraga, 1994). During the era of science education, the importance of making school meaningful and enjoyable to students, with a focus on students' interests and needs, was at the forefront. The progressive era marked a dramatic shift from a classical education to child-centered learning. Proponents of progressive education argued against traditional methods and content, and for content with greater social relevance (Towbridge et al., 2004).

It was also during this same time that educational reformer John Dewey's ideas about progressive education and liberalism were having an impact on secondary schools. John Dewey's influences on *The Cardinal Principles* report were reflected in his call for "using secondary education as an instrument for transforming the everyday lives of citizens in an industrial democracy" (Wraga, 1994, p. 7). Child-centered education called for the importance of real world applications where biology teachers would give students the tools to solve problems in their everyday world, where teachers were guides rather than task makers, and where students should have a say in what they learned (Atkin & Black, 2003). Despite the push against a traditional, classical pedagogy in biology education, many teachers clung to the old ways of instruction such as memorizing facts and having students complete trivial tasks (DeBoer, 1991).

In a push against traditional methodology in secondary science education, the rise of the inductive science laboratory became popular thanks to the contributions of William Kilpatrick and “The Project Method” (1918). Kilpatrick argued that the laboratory should be used for authentic inquiry activities. The Project Method allowed students to solve problems that interested them and had social relevance (DeBoer, 1991). Many educators found the idea of the Project Method appealing, yet, very few incorporated the problem-solving lab approach into their curriculum. This trend was due to issues such as limited lab space, and conflicts in scheduling lab time. Many secondary science teachers found it easier to use book recitations and formalized lab activities, where the lab was used “mainly for confirming the principles presented in the lecture” (1991, p. 110), which was the exact opposite of the inductive approach.

Secondary biology education during the progressive era served as a transition point in between general science, which was taught in the 9th grade, and chemistry and physics which were taught in the 11th and 12th grades respectively. For nearly forty years during the progressive era, biology was most commonly a sophomore class (Atkin & Black, 2003). During the progressive era, secondary biology course content was haphazard, and there was a lack of direction as to what content should be taught, and which topics in biology were the most important (Towbridge et al., 2004). For instance, an article in 1930 describes how high school biology teachers were confused about what content to teach the average students in their classrooms. Many teachers still required students to memorize Latin scientific names, learn about the importance of brushing their teeth, perform field work and independent projects, memorize crayfish reproductive structures, all based on the teacher's various whims and fancies about what biology subjects were most important (Kinsey, 1930).

One of the main factors that led to the decline of progressive education was the start of World War II and the drain it placed on the American school system. The sudden need for scientists and engineers whose technological skills would benefit the war effort left American universities with a shortage of personnel. At the same time, the number of students entering college who were majoring in science declined dramatically during the war years. Also discovered was that many of those being recruited into technology related military fields had learning gaps in science reasoning and basic literacy (DeBoer, 1991). These shortfalls helped fuel criticisms of progressivism.

Critics of progressive education also believed that the curriculum of progressivism was out of touch with what students needed to learn, that the pedagogy lacked the structure and discipline that students required and that the deficiencies that schools were experiencing were caused by progressivism (Atkin & Black, 2003). Eventually, opposition to progressivism grew so strong, that in 1955 The Progressive Education Association ended its operations (2003). Other influences on the decline of progressive education include further complaints of college intrusion in secondary curriculum, standardized testing, a lack of goals in science education, and the "failure to distinguish between learning and memorizing" (Aptekar, 1945, p. 33).

The Space Race and Biology Curricular Reform: 1950's - 1960's

With the launch of Sputnik in October of 1957, a major science education reform in the modern era began. As one researcher argues, "the first step in any reform of our science curricula must be the recognition that the country is now on the wrong track" (Haber-Schaim, 1998, p. 296). The United States found itself lacking in scientific and technological ability when the Russians made the first entry into space. There was a government call to recruit America's "best and brightest" students into becoming scientists to help counter the threat of the Soviet Union. Incentives like high school advanced placement courses were developed to fast-track students into college science programs. The reforms in science education that took place during the Cold War were dramatically different from previous reforms. The focus was now on allowing students to experience and "understand the science that scientists know," and to give students the opportunity to develop and practice the skills that scientists use to study the natural universe (Yager, 2000). The curricular reform movement that resulted was an objection to the "life adjustment" education that was championed by the progressive movement, which allowed for increased application of science to everyday life, and the reform represented a shift towards mastery of subject matter (Pea & Collins, 2008).

During the Cold War, the secondary science curriculum was purged of the topic of technology, including technical careers. Textbooks became the primary way to control the content, and direct instruction was the most common pedagogical approach, although open-ended "inquiry" labs were common (Yager, 2000). During this era, high school student populations continued to increase, including enrollments in science courses, although there was declining interest in the physical sciences (Towbridge et al., 2004). The Federal Government realized that there were few people qualified to enter science careers and that there was a shortage of scientists. America's embarrassment over the USSR's space program allowed for the creation of the National Science Foundation to attract gifted students into science and the space program (Atkin & Black, 2003). At that time, biology was presented in textbooks as fragmented bits and pieces, and little integration between topics was made (DeBoer, 1991). In an attempt to reform secondary biology education, curricular reforms were made, starting with the Biology

Sciences Curriculum Study (BSCS) program in 1958. During that same year, the National Defense Education Act (NDEA) was passed by Congress, which provided funds for the development of updated science textbooks through a grant from the National Science Foundation (Biological Sciences Curriculum Study, 2014). In the late 1950's, the only science course that over half of American students took, was biology. In 1960 BSCS began to create improved biology programs that focused on concepts instead of facts, and investigations instead of lectures. The greatest change in the BSCS biology reform effort from previous reform efforts was the move away from real-world applications and technology, and towards a restructuring of biology as a discipline (DeBoer, 1991).

The New Progressivism and Scientific Literacy: Late 1960's - Early 1970's

In the late 1960's, and early 1970's, fears about competing with the Soviet Union were fading, and the focus once again turned back to providing science education in an equitable and exciting way. The social atmosphere at the time seemed to negate the call for academic rigor found in the late 1950's, and the focus was towards educating all students and not just elite students who would become NASA engineers (Atkin & Black, 2003; DeBoer, 1991). While nearly half of all high school biology courses were using one form of the BSCS curriculum, many schools were using Holt textbooks due to a backlash against teaching evolution. This backlash was due to the comparisons made between animal and human behavior found in a textbook series created by the National Science Foundation (NSF) (Pea & Collins, 2008). Because of this backlash, the NSF stopped all curriculum development. Additionally, the biology curriculum was criticized for not emphasizing the life relevancy of real world science to students, and that it did not motivate students to learn science.

Scientific literacy became the “catch-word” of the early 1970’s. Many educators thought that becoming scientifically literate was a way to improve student interest in science due to the shift towards the new progressivism of the time (DeBoer, 1991; Pea & Collins, 2008). There were many debates as to what “scientific literacy” entailed. The brief re-emergence of progressivism in this era resulted in the open classroom movement, which was not based on Dewey’s philosophy, but as a result of 1960’s romanticism (Zilversmit, 2014). Open classrooms focused on students “learning by doing” as a push against teacher-led classrooms. Students learned at their own pace, and teachers helped students negotiate different subjects. The open classroom movement faded out by the 1980’s with the decline of new progressivism (Cuban, 2014). In the time between the 1970’s and 1980’s, critics of the state of science education during this decade claim that there was a noticeable decline in science education, and little innovation was occurring in secondary science classrooms. For the most part, these declines were due to science courses that were too difficult for the average student. The courses were too discipline oriented and difficult to teach, and science courses were mostly theory and dogma based, leading to science courses that were not connected with general education (Towbridge et al., 2004).

Cognitive Science, “A Nation at Risk,” and the Standards Movement: 1980’s

In 1983, President Ronald Reagan presented a 36-page report, “*A Nation at Risk*,” which drew a massive amount of attention from the media as to the declining state of American education (Graham, 2014). The report, written over 18 months by the National Commission on Excellence in Education, laid out a bleak picture of the direction that the American education system was heading. The report was written in response to a new national crisis in education and politics resulting from instability in the economy due to the perception that Germany, Japan, and other nations had surpassed the United States in education (Yager, 2000). One of the drastic steps that the report recommended was the challenge to develop and adopt "more rigorous and measurable standards" for learning (National Commission on Excellence in Education, 1983). Thus, the modern standards movement was born.

Another aftereffect of the publication of *A Nation at Risk* was the National Science Foundation's funding of research to study how humans learn, thus launching the field of cognitive science. In the 1980's, the development of the digital computer opened the door for researchers to develop new approaches understanding how students learn and understand concepts (Pea & Collins, 2008). Researchers were interested in understanding the differences in how experts and novices conceptualized scientific problems and argued that science teachers need to experience conceptual change themselves so that they can reflect on the process (Carey, 1988). Furthermore, teachers should help students overcome their misconceptions by constructing learning environments that help students better see the understandings and misunderstandings that they bring with them while learning about science (Pea & Collins, 2008).

An additional focus of cognitive scientists during this time was to develop computer-based learning environments that would better help students learn science. Although the cognitive science movement had significant repercussions in the development of cognition theory, which would in turn have a future influence in science education reforms, it had minimal impact on the American educational system for several reasons. First, curricula were never developed that allowed for nationwide implementation. Also, the technology that was required to measure students in their learning environments was too costly, and it is hard to align cognitive science with science curriculum (Pea & Collins, 2008). Finally, while some computer learning modules were developed for biology, their widespread use in secondary biology classrooms never occurred.

Project 2061 - Science for All Americans and Benchmarks for Science Literacy: 1985 -1993

The American Association for the Advancement of Science (AAAS), commissioned Project 2061 in 1985, which was led by science educators, curriculum developers, scientists, and assessment experts to reform science education in the United States. Project 2061's goal was to create a long-term initiative to help all Americans become literate in science, technology, and mathematics (Holliday, 2003). In 1989, AAAS published *Science for All Americans*, which made recommendations for what all students should know in the areas of science, mathematics, and technology by the time they graduate from high school (American Association for the Advancement of Science, 1989). The expert panel attempted to identify the "habits of mind" critical to science, critical skills and ideas relevant to science, and the unifying themes in science (Pea & Collins, 2008). It was through the landmark recommendations in *Science for All Americans* that the groundwork was laid for the national science standards reforms of the 1990's, and beyond.

In 1993, the Oxford University Press published "*Benchmarks for Science Literacy,"* as a result of more than three years of work conducted by *Project 2061*. The publication was in cooperation with over 1,300 university consultants, teachers in six school districts, and scientists (American Association for the Advancement of Science, 1993). The impact on secondary biology education because of *Benchmarks for Science Literacy* was for the first-time recommendations were made to suggest what all students should know topics in biology by the completion of 2nd, 5th, 8th, and 12th grades. In addition to biology, suggested topics in other science content areas, mathematics, and technology were described. Table 1 lists the secondary biology content as suggested in *Benchmarks for Science Literacy* (1993).

Table 1

Benchmarks for Science Literacy - Biology Related Standards

Chapter 5 - The Living Environment (pp., 99-126)	Chapter 6 - The Human Organism (pp., 127-150)
Diversity of Life	Human Identity
Heredity	Human Development
Cells	Basic Functions
Interdependence of Life	Learning
Flow of Matter and Energy	Physical Health
Evolution of Life	Mental Health

The biology topics suggested in Chapter 5 of *Benchmarks*, the living environment, are more suitable for a general biology class, while topics in Chapter 6, the human organism, are more suited to an advanced secondary anatomy and physiology course. Curiously, deemphasized in *Science for All Americans* are botany and zoology content, which are loosely integrated throughout several standards. Ecological topics are included in the independence of life standard, the flow of matter, and the energy standard. In the light of these exclusions, the authors suggested that educators should decide what content to include or exclude in the core curriculum, why to teach the content, and how to teach it (American Association for the Advancement of Science, 1993).

The American Association for the Advancement of Science's Project 2061, proved to be a truly long-term science education reform initiative, with the publications of the *Blueprints for Reform* in 1998, *Designs for Science Literacy* in 2001, and the *Atlas for Science Literacy, 1 and 2,* in 2001 and 2007. Equally important, ideas from Project 2061 were integrated into the Next Generation Science Standards (National Research Council (U.S.). Committee on a Conceptual Framework for New K-12 Science Education Standards., 2012).

The National Science Education Standards: 1996

In 1992, as a result of a call by the National Governors' Association to raise standards in education by developing clear national performance goals, and following the example of AAAS, the National Research Council began to work developing *The National Science Education Standards* (NSES) for K-12 science education (National Research Council, 1996). The goals of the NSES standards were to allow each state to develop their science frameworks by providing them with a guiding framework by which each state could develop standardized assessments (Pea & Collins, 2008). The National Science Education Standards outlined what students should understand and know to be scientifically literate at certain grade levels. Additionally, expanded standards were developed which allowed the quality of science education programs to be evaluated, suggestions as for how to assess and measure student understanding, and the creation of standards for teacher professional development (2008). Also, the NSES suggested that changes be made in the educational system by altering emphasis in areas such as more student-centered learning, more teacher collaboration, and increased inquiry-based learning (National Research Council, 1996, p. 52).

The National Science Education Standards reveal a shift towards topics in molecular biology, perhaps in response to continued advances in the genetics and DNA technologies. Ecological content can be found in the interdependence of organisms' standard, and like in *Benchmarks*, botany and zoology are deemphasized and are again loosely integrated throughout several standards. Perhaps the most controversial focus of the National Science Education Standards at that time was the focus that it placed on inquiry-based science instead of rote memorization. While inquiry-based learning has been shown through research to be the most effective model to teach science, it lies in conflict with standardized multiple choice testing (Brady, 2008).

The Need for New Science Standards: Carnegie Foundation 2007

In 2007, a group of public and private leaders, together with a group of distinguished researchers, were commissioned by the Carnegie Foundation to explore why mathematics and science students in the United States were performing far below other nations (NGSS Lead States, 2013). Recent negative developments such as lagging student achievement, a diminishing share of high-tech exports, and a reduction in America's competitive economic edge, sounded the alarm for improving technological and scientific literacy and preparing students for careers in the modern workforce and set in motion a new push for new science standards (2013). The commission concluded that American students must have a broad foundation of science and mathematics in order to ensure the nation's economic growth, to preserve a vibrant democracy, and to continue to ensure social mobility (Coleman & Zimba, 2007). The Carnegie Foundation report, coupled with several other recent studies calling for reforms to stop the erosion of the United States' edge in science and technology, launched the next science reform effort (Committee on Prospering in the Global Economy of the 21st Century & Committee on Science, 2007).

A Framework for K-12 Science Education, and the Next Generation Science Standards: 2011 – 2013

After nearly two decades of standards-based science education reforms, *A Framework for K-12 Science Education* was published in 2011. This groundbreaking science standards reform initiative draws on many previous science education standards' reforms including; *Science for All Americans* (1989), *Benchmarks for Science Literacy* (1993), and the *National Science*

Education Standards (1996). Other contributors to the *Framework* are the National Science Teachers Association (NSTA), The Carnegie Corporation, and Achieve, Inc. under the umbrella of the National Academy of Sciences, and the National Academy of Engineering. The committee's work was intended to provide the framework for the Next Generation Science Standards (1996).

The Committee on a Conceptual Framework for New K-12 Science Education Standards realized that even though much progress had been made in previous decades with science education standards' reform, there was still much improvement that could be made. Correspondingly, reforms were being made at the same time in many states in English and language arts, and mathematics (Pratt, 2012).

The *Framework* was designed around three dimensions: scientific and engineering practices, crosscutting concepts, and disciplinary core ideas. The committee contends that science education should be constructed around these three essential aspects, and should be integrated into the science curriculum. The *Framework* also has student-centered overarching goals which focus on scientific literacy in a technologically rich world (National Research Council (U.S.). Committee on a Conceptual Framework for New K-12 Science Education Standards., 2012). There are some marked differences in the *Framework* from previous science education reforms. First, the *Framework* defines and introduces technology and engineering, and discusses their inclusion into the new standards. Science, engineering, and technology are integrated into the standards through content knowledge, engineering design, and scientific inquiry (Pratt, 2012). Secondly, the *Framework* includes recent research published on how students learn, such as The Nation Research Council's *How People Learn: Brain, Mind, Experience and School* (2000a), and the National Research Council's *How People Learn:*

Bridging Research and Practice (2000b), which were used to help format the *Frameworks*' guiding principles.

In biologically related standards reforms, the *Framework* presents four core ideas in the life sciences and 14 component ideas. Major changes are seen in the focus of biology content in the Frameworks' four core ideas and 14 component ideas. Cells have been reduced in the standards, and there is a much greater emphasis on ecology and ecosystems. Additionally, as in the last two major standards reforms, zoology and botany have been eliminated in the standards. Genetics and evolution are still predominant, and molecular biology is not as emphasized as it was in prior reforms. Anatomy and physiology are also diminished. The saying that high school biology curricula are "a mile wide and an inch deep" should no longer apply under the new standards.

Perhaps the greatest shift found in the *Framework* is the movement from scientific inquiry to "science practices." The author describes the evolution that occurred in the 1960's reform movements from the methods of science, to the processes of science (Pratt, 2012), as a means to de-emphasizing the memorization of scientific facts and movement towards learning science processes. A similar "de-emphasizing" has recently taken place between scientific inquiry, and a new focus on scientific practices, because of research into how students learn science by the National Research Council (2000a). The Framework suggests eight science and engineering practices which should guide learning, and are shown below: .

1. Asking questions and defining problems;
2. Developing and using models;
3. Planning and carrying out investigations;
4. Analyzing and interpreting data;

5. Using mathematics and computational thinking;
6. Constructing explanations and designing solutions;
7. Engaging in argument from evidence;
8. Obtaining, evaluating, and communicating information (Pratt, 2012, pp. 36-38).

The increased emphasis on science practices instead of inquiry will hopefully encourage teachers to design hands-on investigations. It appears that science and engineering practices in the *Framework* if adhered to, could radically transform secondary biology curricula by creating classroom environments that centered on problem-solving.

The final draft of the Next Generation Science Standards (NGSS) was released in the spring of 2013. The new standards were written as a joint effort of the National Science Teachers Association (NSTA), the National Research Council (NRC), the American Association for the Advancement of Science (AAAS), Achieve Inc., a Washington, D.C. educational group who coordinated the project, and 41 educators from 26 states. Experts in education believe that NGSS "represents a seismic shift" in science education standards reform (Schachter, 2013). The National Research Council of the National Academies "*A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas"* (2012) provided the framework for NGSS.

The NGSS represents a significant progression in the science education standards reform movement that began nearly two decades earlier with the publication of *Science for All Americans* (American Association for the Advancement of Science, 1989). One of the main differences in NGSS is the focus on student performance expectations, which places emphasis on science processes rather than having students memorize facts and formulas (Schachter, 2013). The life science performance expectations that were proposed in the *Framework* remain the same in NGSS. However, they are organized by discipline in the following format; PS: Physical Sciences, LS: Life Sciences, ESS: Earth and Space Sciences, and ETS: Engineering, Technology, and Applications of Science. Additionally, the life science standards are explicitly identified by grade level from elementary grades (K-5), middle school (6-8), and high school (9-12). Each of the four disciplinary core ideas (DCI's) are consistent throughout the grade levels, but the component ideas (CI's) are specific to what students should learn at each grade level. This longitudinal progression of the standards' component ideas attempts to ensure the continuation of concepts across grade level curricula.

In the NGSS, each component idea (CI), when selected by grade level, provides not only the understanding that students should be able to demonstrate in each CI, but a clarification statement is also given to describe the specific concepts that should be learned in each CI. Finally, assessment boundaries are provided for each CI that provide guidance as to what level a component idea should be assessed. Lastly, crosscutting concepts in each of component ideas are also made available. While the standards initially seem difficult to navigate, familiarity with the structure does not take long to become accustomed to.

One of the most prominent changes in NGSS is the addition of engineering as one of the core ideas along with the more traditional core ideas of life science, and physical science. Earth science also is included as a core idea. Earth science and engineering practices are such an integral part of NGSS that their inclusion will almost certainly become a part of the biology curriculum (Willard, Pratt, & Workosky, 2012). Ecology, and more specifically human impact on the environment, have the most prominent topical position in the life science portion of the NGSS. Ecology's importance in standards reform first emerged in the National Science Education Standards (1996), but human impact on the environment in that reform was as a subset of the science content learning strands. In the NGSS, human impact is now embedded in both the ecology learning strand and the core life science strand. Researchers are currently attempting to determine the most efficient way to incorporate ecology and human impact on the environment into the secondary biology classroom (Wyner, Becker, & Torff, 2014).

An Analysis of Trends in Science Education Reforms in the United States

In the next section, an analysis was made to compare the major science education reforms that have occurred in the United States during the last several centuries. This analysis reveals cycles and trends in both curricular and pedagogical aspects of biology education, curricular trends in science education reform are seen in the cycles of classical, progressive, and standards-based reforms. The decline of classical science education by the end of the 19th century was fueled by reform efforts suggested by higher education to clarify college admission standards. The influence of higher education on science curriculum has been a constant pressure on secondary science education since that time. The rise of progressive education and a more student-centered curriculum functioned well when the United States was dealing with the Great Depression, and social issues were at the forefront. It becomes apparent that each time military or industrial demands for more scientists and engineers occurs, there is a shift back towards more traditional modes of education. These shifts could also correspond to changes in the American political climate, but that assumption would need to be researched further.

Science education reforms seem to swing back towards creating more scientists and engineers when there is competition between other industrialized nations and the United States. This trend occurred during World War II, after *A Nation at Risk* was published, and in 2007, after the Carnegie Foundation report was released leading up to the call for more science and engineers in NGSS. A shift back towards liberal progressivism seems to occur when social issues are at the forefront of American culture as took place during the second wave of progressivism in the 1960's and 1970's, which corresponds to the social unrest of the 1960's.

Another curricular trend that emerges is the biology content itself. In most of the American science education, biology was taught mainly at the macro level with the predominance of botany, zoology, and physiology. The curricular focus of biology content shifted more towards the micro, or molecular biology level, with the dominance of BSCS texts, and it remained predominantly at the cellular level until the Framework and the NGSS. Now the biology curricular focus has turned back towards the macro with ecology and evolution as the main biology content focus. What accounts for this curricular shift? Perhaps the fundamental shift in biology curricula towards the micro was in response to the genetics revolution which began when Watson and Crick described the structure of DNA in 1953, and many of the cutting-edge advances in biology over the subsequent decades have been in genetics and biochemistry.

One new trend that emerges in American science education reforms is the tension that exists between direct instruction, memorizing facts, inquiry or science processes, and standardized testing. With the incorporation of standardized tests in the early 1900's to allow for easier sorting of students for college admission, tension has since existed which favors memorizing facts that are more easily assessed on standardized tests and developing students with scientific reasoning skills learned through investigations. In the National Education Science Standards (1996), educators are pressured to produce students who will do well on multiple choice standardized tests which are much easier to grade. Free response exams, which are exceedingly difficult and time-consuming to grade, are more aligned with assessing students' science reasoning skills. This tension exists in high school science classes as well, where a teacher may have 130 exams to grade in a setting, and grading free response exams in that number is overwhelming on several levels. This dilemma pushes science teachers back towards assessing facts about science instead of science processes, and the most efficient way to teach facts about science that students can memorize is through book work and direct instruction which have been the dominant means of education in American education throughout its history. These concerns about assessments and the NGSS were recently the topic of debate by researchers (Sparks, 2013). It was argued that with the shift in focus towards science practices, that the concern is how to create assessments that measure how well students develop conceptual models, communicate research findings, and follow lines of investigations. Critics are skeptical of how standardized tests can capture the "how" of student learning, a truly daunting task. They suggest that stakeholders take their time and think about issues such as assessment instead of rushing into the NGSS. Sparks argues that the NGSS is not a federal law, and the reform should not put assessment before instruction (2013).

The Future of Secondary Biology Education in the Coming Decades

The Next Generation Science Standards bring the promise of emphasizing science processes instead of memorizing science facts (Schachter, 2013). The NGSS also places students at the center of learning, which is a progressive value. Perhaps the NGSS will finally succeed in creating scientific literacy for all students instead of just the best and brightest. What impact will NGSS have in the coming decades? Will the NGSS become a casualty to the next science reform movement, or will it become the impetus for real reform in American science education?

The success of NGSS will be determined by what happens in the next few years during its implementation phase. First, if a state chooses to adopt NGSS, the state department of education and local school districts have the responsibility of providing assessments, learning materials, and activities to local science educators (Schachter, 2013). Teachers must be provided with high quality, professionally developed instructional materials that align with NGSS, instead of being asked to prepare the materials themselves. With the ever-increasing demands on secondary teachers due to new teacher evaluation instruments and a prescribed school district pedagogy, it is unlikely that secondary biology teachers will have the time or resources to develop instructional materials that truly allow students to learn science practices. Instead, many teachers may resort to shuffling materials they have used for years to see where they can "fit into" the new standards. Likewise, intensive teacher re-training must take place to help them prepare for the transition to the NGSS.

Unfortunately, there are few high-quality teacher resources available to secondary biology teachers that are based on the NGSS principles. Martin Shields classic; *Biology Inquires: Standards-Based Labs, Assessments, and Discussion Lessons* (2006) provides standards-based inquiry labs for secondary biology teachers. This valuable resource was well ahead of its time, and the activities presented in *Biology Inquiries* reflect aspects of three-dimensional learning. More recently, the National Science Teachers' Association published two groundbreaking instructional resources that align with NGSS standards. First is *Scientific Argumentation in Biology: 30 Classroom Activities* (Sampson & Schleigh, 2013), second is *Argument-Driven Inquiry in Biology: Lab Investigations for Grades 9-12* (Sampson et al., 2014). Biozone recently released a new resource book, *Biology for NGSS* (Allan, 2014), but upon inspection, alignment of the course content with the NGSS was questionable. Another student-centered book that was recently published called *Translating the NGSS for Classroom Instruction* answers frequently asked questions that science teachers may have concerning the NGSS implementation (Canipe, 2014). The author notes that many currently utilized classroom materials are not well suited for use in NGSS, and he gives practical suggestions on how to translate current practice into an NGSS classroom. For the NGSS to succeed, more resources such as these must be developed for secondary biology teachers.

In future decades, there will most certainly be new science education reforms. What will be most telling is if the next reform movement is an extension of the standards movement and if it builds off prior reform efforts such as NSES and the NGSS, or if a radical departure from the standards will occur due to the NGGS's failure to reform science education. If this is the case, the next science education reform may swing back to a more student-centered, progressive approach. This may occur if it is found that NGSS is a reform that is once again focused on turning the nation's best and brightest into scientists and engineers while neglecting the average student's need to have a practical and well-rounded scientific view of the world in which they live. One recent article claims that the NGSS was written with "all students in mind," as it provides the groundwork for students to earn a college degree in science through a rigorous science education, that will hopefully end with a career in science (Maxwell, 2013). Yet, it is understood that very few average students go on to earn degrees in science. On the other hand, producing students who are scientifically literate and who have good problems solving skills would obviously benefit from this whatever their futures hold. If states and school districts do their part by providing high-quality training and materials to teachers, the NGSS may have a better chance at creating these scientifically literate American citizens.

What do contemporary practitioners feel about their chances of being prepared to take on the NGSS as meaningful science education reform? 83% of teachers in a recent survey believe that the NGSS will improve student learning, 58% do not think their school districts will give them the appropriate classroom materials, 59% are not confident that the necessary equipment will be accessible, and 68% of teachers surveyed believe the additional training needed to implement the NGSS will be available (Mervis, 2013).

K-12 Stem Education

The public's awareness of the need for science, technology, engineering, and math education (STEM) has recently increased. According to the U.S. Department of Education, large increases in STEM-related jobs are expected by 2020, yet few students today are gaining expertise in STEM-related fields (United States Department of Education, 2016). Fortunately, the NGSS and the *Framework* for K-12 science education provide an important new path for STEM education (Dorsey, 2013). The STEM initiative began well over a decade ago in an effort to integrate engineering practices and technology into science and math courses, yet there is still no broad consensus on what constitutes STEM education and how it should be taught (Mitts, 2016). The NGSS has a goal of making the four STEM fields of science, technology, engineering and mathematics relevant to students' everyday lives by strengthening the engineering aspects of science and engineering practices (NGSS Lead States, 2013).

Teacher Change

Teachers are particularly resistant to change, especially when the change impacts their teaching practices or themselves personally (Flett & Wallace, 2005). Researchers who have studied the process of teacher change found that for a variety of reasons, people resist change when moving from what is known and comfortable, to a new way of acting and thinking (Fullan, 2010). The National Science Teachers Association (NSTA) asserts that experienced teachers must make significant shifts in both the way they teach and in their course content for the NGSS to succeed (National Science Teachers Association, 2013). Researchers have also found that for teachers to change their practice, they must make a critical self-evaluation of their pedagogy

(Long, 2011). One way they suggest that teachers can accomplish change is using the Quality Teaching Model (QTM), which allows them to make critiques of their own pedagogy and critical reflections of their own practice. The QTM consists of three dimensions that support in-depth critical reflection based on rigorous observation during which data is gathered and then analyzed (Ingvarson, Meiers, & Beavis, 2002). Similarly, self-study research methodology may be used in a likewise manner as a vehicle for teachers to elicit change in their practice. This is accomplished as they begin to understand and reform their professional identities, test, and model effective reflection, and most importantly, push the boundaries of their pedagogy (Hicks et al., 2004). For the NGSS to become a successful science education reform, a significant number of science teachers will need to make changes to their pedagogy and course content.

Theoretical Framework

The theoretical framework in a research study provides a strong scientific research base for the study, gives support for the rest of the thesis, it gives scientific justification for the study and is based and grounded in scientific theory (Vinz, 2015). The theoretical framework in this study draws on four practitioner research modalities that are closely related: Action research, self-study teacher research, personal history self-study, and reflective teaching.

Action Research

Practitioner research, where practitioners carry out research on their own practice, is the overarching research body that encompasses teacher research, action research, reflective practice, self-study, and other offshoots in this research modality (Vanassche & Kelchtermans, 2015). Action research has been defined in the following way:

> Action research is inquiry or research in the context of focused efforts to improve the quality of an organization and its performance. It typically is designed and conducted by

> practitioners who analyze the data to improve their own practice. Action research can be done by individuals or by teams of colleagues. The team approach is called collaborative inquiry (Rigsby, 2016, para. 1).

Action research had its origins in the late 19th and early 20th centuries as a problem-solving method in the work-place, but its use was criticized as a research method in education by quantitative researchers (Samaras, 2011). However, action research gained more credibility in the 1980's as a tool for curriculum planning reform, and with the development of the cyclical format.

While teacher self-study is related to action research, some key similarities and differences exist. First, both self-study and action research are research methodologies that allow teachers to improve their teaching through classroom problem solving (Feldman, Paugh, & Mills, 2004). However, in action research, the overarching goal is to produce "action" as a way of changing the classroom, while in self-study the focus is on changing one's "self" as a way to impact student learning (Samaras, 2011). Also, in self-study research, there is not a particular prescribed way of conducting research, as researchers are encouraged to use multiple methods to acquire understanding, while in action research the spiral of investigation is used to guide their research (2011).

Self-Study Teacher Research

This research study is guided by self-study teacher research as its theoretical framework. Reflecting on and changing my practice is the guiding goal in this study, and self-study research is the vehicle to help bring about change in my classroom. Self-study teacher research allows a teacher to generate knowledge about their teaching by studying their own classroom (Samaras, 2011). According to Samaras (2011), self-study teacher research is based on the Five Foci

Framework format which helps outline the methodological components of self-study. Samaras' Five Foci are listed below:

1. Personal situated inquiry which allows teachers to draw from their own personal experience which is situated in their classroom.
2. Critical collaborative inquiry through feedback from others with alternate perspectives and divergent views.
3. Improved learning allowing teachers to study their teaching, and then work to improve and better understand their profession.
4. Self-study is a systematic and transparent research process which relies on clear, open, and honest descriptions of practice.
5. Self-study research generates knowledge and contributes to broad knowledge base through personal and professional development, and in the educational community (Samaras, 2011, pp. 10-11).

Teachers can use self-study research to improve their practice. Research is conducted by first designing a study, researching the ethics of the study, then collecting data, and finally by writing up the findings and presenting them (Samaras, 2011). The self is the focus of study in self-study research with the goal of "leading to a reframed understanding of one's role in order to impact students' learning" (p.57). Because the researcher is a resource during the research, teachers improve their practice when they "problematize their selves in their practice situations" (Feldman et al., 2004).

As a research methodology, self-study allows teachers to look at their own education-related life history experiences; it allows teachers to explore the insights they discover into how they think about learning (Samaras, 2011). In self-study:

> The teacher educator him/herself is both the researcher and the main focus of the study. Self-study is concerned with the acquisition and development of teacher educators' knowledge of practice and how such knowledge can inform and enhance learning and teaching about teaching (Berry, 2014, p. 1).

The historical and cultural influences that we experience in our lives help to shape our educational knowledge and influence our development (Vygotsky, 1978). Self-study research will be used as a theoretical framework to investigate why I teach science on the traditional teaching spectrum, and how my practice will change as I teach science in a manner I am not trained in, such as phenomenon-based learning. There is a widely shared belief in self-study research that "teaching is a fundamentally autobiographical act" (Hicks et al., 2004, p. 2). Additionally, self-study researchers agree that "the notion that who we are as people, affects who we are as teachers, and consequently our students' learning" (p. 3). Researchers also argue that teachers, unlike other professionals, enter a workplace in schools in which they have a long history that can often impact the way they teach their students (Hicks et al., 2004).

Self-study is considered a research methodology which offers a variety of reflective methods that enable the researcher to "capture the essence of the question being studied and think deeply about practice, its development, and its impact" (Samaras, 2011, p. 68). The multiple self-study methods have been developed by self-study researchers as tools to collect data, and multiple methods can be used in a study (2011).

The six self-study methods are:

1. Developmental Portfolio
2. Personal History
3. Living Educational Theory

4. Collective Self-Study
5. Arts-Based Self-Study
6. Memory Work Self-Study

For example, personal history self-study research on the life histories of teachers has increased knowledge about how adults change and grow during their careers, and an emphasis is placed on self-reflection as a means to explore the growth of perspective and consciousness in adults (Keegan, 1982; Wilcox, Watson, & Paterson, 2004). Self-study as a research methodology can be used by teachers to increase self-knowing, to reform a professional identity, and to elicit change in the future. Self-study can also be used to assess and model reflective practice, which in turn can transform practices in the classroom that go against the status quo (Hicks et al., 2004).

Reflective Teaching

Like action research, reflective teaching is a cyclical process. Reflective teaching provides teachers with a process to look introspectively at what they do in the classroom, and then decide whether it is working. In reflective teaching, educators utilize a process of self-observation which is followed by self-evaluation (Tice, 2004). One of the first researchers to advocate reflection as a specialized form of thinking was John Dewey (1933), who considered reflection as a reaction to a situation one had experienced where perplexity, doubt, or hesitation had been experienced. In the 1980's, Schon used Dewey's work as a basis for 'reflective practice,' which detailed how practitioners could use an awareness of their implicit knowledge to learn from their experiences (1983). While reflective practice can be an effective and methodology to transform practice, researchers warn that if reflective practice is carried out by over-worked practitioners, the process can become a routinized checklist that could result in ritualized reflection (Finlay, 2016).

Theoretical Underpinnings

The theoretical underpinnings of a research study are the motives, devices, or sets of ideas that justify or form the basis for the research study (The Oxford Pocket Dictionary of Current English). The theoretical underpinnings for this personal history self-study are active learning, modeling instruction, phenomena based learning, constructivism and social constructivism, conceptual change theory, and metacognition.

Active Learning

There is an increasing call in education to engage learners in active learning. Active learning is a discourse that has emerged from the lifelong learning agenda, which asserts that lifelong learning should be the norm and that active learning provides the types of dispositions and skills that are necessary for lifelong learning (Drew & Mackie, 2011). Researchers believe that while all forms of learning are "active," certain types of learning can be more active than others, especially those types which encourage the construction of understanding and knowledge, in contrast, to passively received learning (Watkins, Carnell, & Lodge, 2007).

According to Drew and Mackie (2011), active learning can be viewed as incorporating the following three dimensions:

1. Behavioral: The active employment and development of resources.
2. Cognitive: Active thought about experiences to make sense and so foster construction of knowledge.
3. Social: Active interaction with others on both a collaborative and resource-driven basis. (2011, pp. 455-456)

Active learning aligns to the *Framework for K-12 Science Education* (2012) and the NGSS (NGSS Lead States, 2013), as it promotes learning while students are engaged in activities such as discussion, problem solving that fosters analysis, the evaluation of class content, synthesis reading, problem-based learning, cooperative learning, and simulations and case methods ("Active learning," 2016; Franzen, Herman, & Goodsell, 2007; Ueckert & Gess-Newsome, 2008; Welsh, 2013).

Modeling instruction

Modeling Instruction (MI) is a pedagogy based on science education research that was first developed in the 1980's (Haag & Megowan, 2015). Modeling Instruction has as its foundation the eight science and engineering practices of the NGSS, which is one of the three cornerstones of the science education reform (2015). Modeling Instruction uses a model-centered curriculum to integrate a student-centered pedagogy through the application of inquiry techniques that are structured to teach basic skills in proportional reasoning, data analysis, critical thinking, the formulation of hypotheses and the evaluation the hypotheses through evidence and rational argumentation (Haag & Megowan, 2015; Hestenes, 1987). According to researchers, a model is a conceptual representation of a real object's structure, and mental models are a representation of a corresponding representative structure, both of which can be developed by students as mental tools to make better sense of a physical reality, which allows them to answer questions and make predictions (Hestenes, 1987; Johnson-Laird, 1996).

Modeling Instruction is a three-phase instructional activity based on Karplus' Learning Cycle (1977), and Hestenes' Modeling Cycle (1987). In the first phase of model construction, the instructional unit begins with a paradigm which reveals a relationship that exists between two physical systems or structures. In the second phase, the student validates the model through refining the original model that they constructed, and by testing it in conditions that are different from the initial conditions. In the third phase, model deployment, the model is used by the student to solve a variety of different problems in different contexts (1987).

Phenomenon-Based Learning

According to the NGSS, phenomena are observable events that students can use the three dimensions to explain or make sense of (NGSS Lead States, 2013). The NGSS suggests that three-dimensional learning is what students should experience in classrooms that have implemented and are using the elements of the three dimensions in unison, allowing students to design solutions to problems and to explain phenomena (2014). The two types of phenomena are lesson-level phenomena, which help students discover and figure out the smaller pieces of the big picture, and anchoring phenomena, which most often takes students an entire unit to come up with a scientific explanation of the phenomenon (Maltese, 2016).

According to Maltese (2016), in a phenomenon driven science classroom, the learning is led by the students. Students are given questions, not the answers, which encourages richer engagement with the course content as students must actively figure out the core science ideas, instead of just passively learning about the content. This shift in the NGSS towards phenomena driven science is needed, as researchers have found that lab-based instruction in biology has mostly focused on engagement and motivation of students, but there is a lack of authentic opportunities for students to explore phenomena (Puttick, Drayton, & Cohen, 2015).

Constructivism and Social Constructivism

Constructivism is a worldview that views learning as a process that is active and constructive where the learner actively constructs information from prior knowledge and experience ("Constructivism," 2016; Driver, Asoko, Leach, Mortimer, & Scott, 1994). Students do not “acquire” knowledge in constructivism, as it is constructed from interactions with the environment and personal experiences. Cultural factors and past experiences of the learner contribute to their construction of knowledge. One of the foundations for constructivism is Vygotsky’s social development theory (1978). Constructivism impacts learning through the promotion of a curriculum that is customized to the prior knowledge of the student, where teachers rely on instructional strategies that enable students to interpret, analyze, and predict information, and through the reliance on extensive student dialogue and open-ended questions ("How constructivism impacts learning," 2011).

The research in this study is grounded in constructivism, which is an ontology and epistemology that provides a theoretical framework which focuses on the “meaning-making” or “sense making” of the individual (Orgil, 2007). Constructivism also examines how people engage with experiences in the world and how they are able to make sense of experiences (Bodner, 1986). In the constructivist approach, when a person learns something new, they undergo the process of constructing their understanding from the new experience. Thus, when a person “learns” something, the process involves a perspective change from how they originally experienced a certain phenomenon, to seeing the same phenomenon in a qualitatively different way. This shift in the view of different angles involves the addition of information to a previously held understanding, which then results in the rebuilding of that understanding. This reconstruction of understanding allows a person to experience a shift in their experience of a phenomenon, often in more powerful, richer, and different ways (1986).

Researchers believe that constructivism provides a meaningful theoretical framework for studies that involve a description of a learner’s concepts and cognitive structures (Cobern, 1993). Additional research has shown that when research focuses on how learners make sense of phenomena, that constructivism is an appropriate research lens (Bodner, 2007). From the constructivist viewpoint, when a person learns a new concept, they construct meaning from their personal experience and try to find consistency and order in what is happening in the world around them even when they do not have access to all of the information (Von Glasersfled, 1989).

Social constructivism is an offshoot of constructivism that places emphasis on the collaborative nature of learning. Lev Vygotsky, who was a constructivist, rejected other constructivists such as Perry and Piaget's contention that it is possible to separate learning from its social context ("Social constructivism," 2016; Vygotsky, 1978). While cognitive scientists such as Perry and Piaget viewed knowledge as constructed actively by learners as a response to their interactions with stimuli in the environment, Vygotsky hypothesized that both culture and language have essential roles in how learners see the world and how they develop intellectually ("Social constructivism," 2016). Vygotsky believed that learning as a collaborative process had a profound impact on collaboration in the classroom as it has allowed learners to gain teamwork skills, and it ties the individual's learning, which is a social phenomenon, into the group's success. As a result, the learner becomes connected to a classroom social setting in a manner that helps formulate their identity (Wenger, 1998b).

Conceptual Change Theory

In conceptual change theory, it is believed that learners gain knowledge from their daily life experiences, and conceptual knowledge is greatly influenced by events and natural phenomena that people experience (Ozdemir & Clark, 2007). As a result, a student's formal learning is affected by their prior knowledge, and students arrive at their formal science instruction with "a diverse set of alternative conceptions or misconceptions concerning natural phenomena and events…that are often incompatible with scientifically normative ones" (2007, p. 356). There are, however, several different divisions in conceptual change theory. One of the most influential conceptual change theories corresponds to Piaget's ideas about accommodation and Kuhn's notion of a paradigm shift. It is proposed that if a student can use their current conception to solve problems in an existing conceptual schema successfully, then need to correct the current conception is not required by the learner (Posner, Strike, Hewson, & Gertzog, 1982). Researchers contend that students must become dissatisfied with the initial conception so that they will abandon it and experience conceptual change by accepting a scientific conception. A principal goal is to "create a cognitive conflict to make a learner dissatisfied with his or her existing conception" (Ozdemir & Clark, 2007, p. 352).

Other researchers believe that the process of conceptual change occurs with the formation of mental models (Ioannides & Vosniadou, 2002; Ozdemir & Clark, 2007). These researchers contend that even children at a very young age make predictions about phenomena and develop theories, but their mental models change as they experience formal scientific instruction. Thus, instruction should focus on changing children's mental models. When students combine their initial models with scientific models, sometimes misconceptions may be generated (Vosniadou & Brewer, 1994). Researchers believe that cognitive change results from radical changes that occur during a time-consuming, gradual process, where students restructure and revise their entire network of presuppositions and beliefs (Chi, 2005).

Conceptual change theory has profound implications for instruction. This perspective allows for curricula to be designed that uses the same phenomena in varied contexts to confront students (Ozdemir & Clark, 2007). Using multiple representations of phenomena can help learners highlight different variables within the context, which can lead to conceptual change through organizing, restructuring, and editing ideas.

Metacognition

Metacognition refers to a learner "thinking about thinking," and introspective processes such as developing the best plan to solve a problem, and self-evaluation while solving the problem, are metacognitive practices (Livingston, 1997). The idea of metacognition originated with John Flavell (1979), who believed that metacognitive experiences and metacognitive knowledge could be used as a way to control cognitive processes. Flavell divided metacognitive knowledge into three divisions; understanding the person, understanding the task, and understanding strategy to gain knowledge. He considered these variables key in understanding how people process information, learn and complete a task.

In instructional settings, metacognitive strategies can help learners become more flexible, strategic, self-reliant, and productive in how they learn (Scheid, 1993). One metacognitive learning strategy, Cognitive Strategy Instruction (CSI), is an approach to instruction that places emphasis on thinking processes and thinking skills as a way to enhance learning (1993). This method advocates for the teaching of learning strategies that some of the best students use to other students to improve learning. To accomplish this, students learn through experience to construct knowledge as a way to develop metacognitive control (Livingston, 1997).

Chapter 2 Summary

The literature presented in chapter two provided the background for this research study. In the first section, a history of science education reforms in the United States was introduced which highlights key reform efforts that culminate in the NGSS and its impact on science education. In the second section, a discussion of the current state of K-12 STEM education in the United States tied its importance in with the goals of the NGSS. In the third section, literature on teacher change was discussed. Next, in section four, the theoretical framework of the study was presented through subsections on action research, self-study teacher research, and reflective teaching, all of which are forms of practitioner research that form the theoretical basis of the study. Finally, in section five, literature on the theoretical underpinnings of the study was explored that included active learning, modeling instruction, phenomenon based learning, constructivism and social constructivism, conceptual change theory, metacognition. These underpinning theories have aspects of which will influence this study.

In Chapter 3, the research goals and objectives described in Chapter 1, and the literature review findings from Chapter 2, will be used to describe the study's research methodology in detail. Other study factors will be addressed such as the study's' participants, a study timeline, the setting of the study, and the context of the study. A detailed description both data sources and collection measures will be described along with details about data analysis. Finally, issues related to the study's integrity will be highlighted including rigor, validity, reliability, ethical considerations, and the limitations and challenges of the study will be discussed.

CHAPTER 3 - METHODOLOGY

"The only thing you can change in education is your own practice" (Samaras, 2011, p. 115). The purpose of this self-study is to attempt to change my practice from teaching science traditionally, to adopting a pedagogy that aligns with the three dimensions of the NGSS. What do instances of three-dimensional learning look like in a secondary classroom, and what it is it like for a traditional science teacher to transition to a new type of teaching? What tensions arise during such a shift in pedagogy? These are some of the questions that are addressed in this self-study.

This study is conducted in three phases. Phase I occurs before the enactment of an instructional unit that better aligns to three-dimensional learning, and includes a self-analysis while teaching the traditional ecology II unit. The unit will be analyzed for alignment with the three-dimensions of the NGSS using the EQuIP Rubric for Lessons & Units: Science Version 3.0 (NGSS Lead States, 2013) (Appendix A). Additionally, field notes will be taken during the traditional unit enactment using the Science Lesson Evaluation: Field Notes Google Form (Appendix B). The field notes form was created by modifying the EQuIP rubric. Also during phase I, an evaluation of a teacher-developed instructional unit, the DNA and cell division unit, (Appendix C) using the EQuIP rubric is made, and the results of the analysis are discussed (Appendix D). Next in phase I, a professionally developed unit designed by Project NEURON at the University of Illinois (2016) is selected as an instructional unit that better aligns with three-dimensional learning for enactment in my classroom during phase II (Appendix E). The unit will also undergo an evaluation for its alignment with the NGSS using the EQuIP rubric (Appendix F).

Phase II will occur during the enactment of the study and will include data collection using the Science Lesson Evaluation: Field Notes Google Forms while I am teaching the Project NEURON unit. Phase III will occur after the enactment of the study. Suggestions for how the model Project NEURON unit could be made to better align with the NGSS and three-dimensional learning are made. In this chapter, the research design of the study will first be discussed, which will be followed by the studies' research questions. In the next section, the research timeline, setting, and participants will be described. Data sources and collection methods will then be identified, followed by data analysis methods. Chapter 3 will conclude with a discussion of validity, reliability, and ethical considerations in the study. Finally, the assumptions and challenges of the study will be addressed.

Research Design

As a research methodology, self-study allows practitioners to push the boundaries of teaching, and to reform their professional identities through the testing and modeling of effective self-reflection (Hicks et al., 2004). Reflective teaching has a long history in education, as Dewey (1904) believed that it provided a way for teachers to become both producers and consumers of knowledge, and allowed them to develop theories on learning and teaching. Self-study research is one of the five main branches of practitioner research, which as a methodology provides a way for the practitioner to assume the role of the researcher simultaneously, and allows for an inside perspective into teacher inquiry with the classroom as the context for the study (Cochrane-Smith & Lytle, 2009). A shift in educational research occurred in the late 1990's when qualitative research methodologies became more accepted in a move away from positivistic educational research. This change provided educators with methodologies more aligned to their identities and circumstances (Zeichner, 1999). The introduction of self-study as a qualitative research methodology has been described as “the most significant development ever in the field of teacher education research” (Zeichner, 1999, p. 8). Self-study also has roots in the constructivist movement, which allows teachers to reflect through metacognition on teaching and learning via specially designed curricula (Korthagen & Lunenberg, 2004).

The theoretical perspective of self-study is rooted in postmodernism because of its unpredictable and non-linear nature (Wilcox et al., 2004). Postmodern scholars believe that since the production of knowledge has a cultural aspect, research should take an analytical and reflective stance to explore the interpretive, ideological, and cultural basis that learners build into their knowledge conception (Lassonde, Galman, & Kosnik, 2009).

Researchers agree that as a methodology, self-study research employs multiple methods, and they understand that there is not a single, established “correct” way of doing self-study (Hicks et al., 2004). Researchers also contend that how a self-study is carried out depends on “what is sought to be better understood” (Hicks et al., 2004; Loughran, 2004). In fact, several researchers contend that self-study research is not a process that is linear, that it does not follow a lock-step procedure, but is recursive in nature (Hicks et al., 2004; Samaras, 2011).

Self-study research has a five foci framework. The five parts of the framework are: “Personal situated inquiry, critical collaborative inquiry, improved learning, transparent research process, and knowledge generation and presentation” (Samaras, 2011, p. 10). All five foci are considered and included in the self-study timeline design (Appendix G). As a form of qualitative research, self-study allows for the fluidity of shifting research questions as the study is underway, or changes in pedagogies as literature is reviewed (2011).

Research Questions

The research questions in this self-study correspond to the three different phases of the study. However, the main research question this study is:

1. What issues arise when using self-study to guide my transition from teaching traditionally to teaching a unit that better aligns with the three dimensions of the NGSS?

The research questions for Phase I are:

1. What issues become evident when developing or selecting instructional units that more closely align to the three dimensions of the NGSS?
2. How closely do the characteristics of my practice align to three-dimensional learning when teaching biology traditionally?

The research questions for Phase II are:

1. How does implementing a biology unit that aligns to the NGSS change my instructional methods, and what issues become evident during this implementation?
2. How closely does the Project Neuron unit align to the NGSS and three-dimensional learning?

The research questions for Phase III are:

1. After data analysis, how can the Project Neuron unit be further modified to become more closely aligned with the NGSS and three-dimensional learning?
2. What recommendations and criticisms of the NGSS instructional unit implementation process can be made to help other traditional teachers make the transition using professional development and self-study?
3. Can a self-study be used to guide my transition from teaching traditionally, to teaching a unit that aligns with the three dimensions of the NGSS?

Research Timeline

Self-study teacher research begins with questions about my practice that result from professional discourse and observations in my classroom. In this self-study, the timeline is adapted from the research project plan suggested by Samaras (2011, pp. 25-29). The study will be divided into three phases: Phase I will occur before project enactment, phase II is during enactment, and phase III is after the project enactment. This self-study will take place during three semesters, or over a year and a half timeframe. The research study timeline for this project is outlined in Appendix G. The sequence in each phase is not required to be linear.

Study Setting and Participants

This self-study will take place in my secondary biology classroom at a public high school in East Central Illinois. The school district consists of twelve elementary schools, three middle schools, two high schools, and one alternative academy. The high school where I teach has a total enrolment of approximately 1250 students; 47.6% of which identify as White, 31.3% identify as Black, 9.4% identify as Hispanic, and 7.2 % identify as Asian. 48.2% of the schools' students are classified as low-income ("Illinois report card," 2016). Biology is a required course taken by all freshmen, but the course has accelerated (honors), and academic biology sections. In this study, observations will be made and data collected while teaching my eighth period accelerated biology students.

Data Collection

Data collected in this self-study will be primarily observational. According to Wolcott (2001), observational data can come in the form of videotapes, research logs, and checklists. A research log in the form of field notes will be the primary data source in this study. Research field notes will be kept digitally using Google Forms. The Science Lesson Evaluation: Field

Notes, which have been modified from the EQuIP Rubric for Lessons & Units: Science, were converted to Google Forms because of the platform's ease of data collection and manipulation.

Daily Observations

During phase I and II, classroom observations will occur during my 6th and 8th hour accelerated biology class. The sixth-hour biology class is the first accelerated class of the day, and only critical instances that occur during the class will be noted during my 7th hour plan period. No video or audio recording of students will occur during this period as they are not under IRB protection. During the 8th period accelerated biology class, I will use both video and audio recording devices to capture critical instances, or other notable events, as this class is under IRB protection. To identify an incident as critical it "must occur in a situation where the purpose or intent of the act seems fairly clear to the observer and where its consequences are sufficiently definite to leave little doubt concerning its effects" (Flanagan, 1954, p. 1).

Teacher reflection can be a central focus of action research, and researchers have found that teachers can experience growth in their practice through teacher reflection (Parsons & Brown, 2002; Pellegrino & Gerber, 2012). Video and audio recordings in this study will be used to verify and expand upon critical instances that occur during Phase I and Phase II. Although the recording devices will be active during the daily lessons, only the segments which contain critical instances will be transcribed and coded. A notepad will be carried to record the time when critical instances occur during the lesson to help in later analysis.

Field Notes

The Educators Evaluating the Quality of Instructional Products (EQuIP) Rubric for Lessons & Units: Science, provides the criteria with which to measure the overall quality of units and lessons and their alignment to the Next Generation Science Standards (2013). The EQuIP rubric can be used as a tool for the review of existing instructional materials to determine whether revisions are needed to meet alignment criteria with the NGSS, as is the case in this study. The rubric also encourages productive discourse between educators who are evaluating instructional materials, and as a tool to produce feedback on ways that instructional materials can be better improved so that they better align with the NGSS. With this powerful, evaluative potential in mind, I chose the EQuIP rubric as one of the primary sources of data collection in this study, and I made modifications so it would align with an instructional lesson format instead of a unit evaluation format.

To efficiently record field notes in a digital format, I chose to convert the modified EQuIP rubric into the Google Forms format. The Google Forms format allows for the digital recording of information with several advantages. First, Google Forms responses can be recorded through multiple-choice, text, checkboxes, paragraphs, grids, and scales. The responses are automatically collected in a Google Sheet where formulas can be added allowing the data to be sorted for analysis. Additionally, Google Forms can be shared with others, such as my critical friends, for analysis and critique.

Field notes will be written during four weeks of the first semester, and for four weeks during the Project NEURON unit in the second semester. Immediately following the last period of the school day during the study, I will complete the field notes using Google Forms (Appendix B). The Google Form is laid out in six sections. The first section records the evaluator's name, the observation date, and the evaluation time. In the second section, evidence of three-dimensional learning during the lesson will be registered. First, the lesson's anchoring phenomena, or problem, is identified and the NGSS dimension one, science practices, is selected in a checklist. Following this, a descriptive narrative of any science practices that were observed during the lesson will be entered. Next, the NGSS dimension two: crosscutting concepts, are identified and instances will be reflected upon. The third NGSS dimension, disciplinary core ideas that anchor the lesson will be checked, along with the particular NGSS life science performance expectation which will be selected through a pull-down menu. The final selection in section one is a written reflection of instances that occurred during the lesson where crosscutting concepts were used in the explanation of the lesson's anchoring phenomena or problem.

According to experts who use the EQuIP rubric, if the unit or lesson that is being evaluated does not meet the criteria of containing the essential elements of three-dimensional learning, then there is no need to continue with the evaluation (Krajcik, 2014). In the case of field notes, if NGSS alignment is not evident in section one, then section two may not be completed. If this is the case, the lesson evaluation will continue with section three.

The next field notes section helps identify the instructional supports that were used during the lesson. Section two has been condensed from the EQuIP rubric. The first reflection of section two is a written description of any instances during the lesson where authentic and meaningful scenarios that reflect science practices as experienced in the real world and that provide students with a purpose were used in the lesson. In the second reflection of section two, instances where scientifically accurate and grade-appropriate scientific information, phenomena, and representations were used in the lesson to support students' three-dimensional learning, are identified. The final part of section two reflects the opportunities that are evident in the lesson which allowed students to express, clarify, justify, interpret, and represents their ideas and responds to peer and teacher feedback orally and in written form as appropriate to the student's three-dimensional learning.

Section three of the field notes allows for a written description of formative assessments that were used during the lesson, and well as examples of how concepts learned during the lesson will be incorporated into summative assessments.

Section four of the field notes is the most qualitatively rich section as it entails written lesson reflections. In the first section, notable events that occurred during the lesson will be discussed. If any of these events were captured using audio or video recordings, their transcripts will be made, which is the case in all the reflections in section four. Next, points of tension that emerge during the lesson will be entered, followed by any issues of control that arose during the lesson between the teacher, students, or the content. In the following reflection, any traditionally taught material that was excluded from the lesson due to the lesson's format will be recorded, and in the next reflective section, any instructional shifts that occur during the lesson will be identified and discussed. The last part will allow space for general reflections on the class period and any notable instances that occurred during critical friend's discussions.

Critical Friends

The participants in this study include me as the educator/researcher, and two critical friends. Central to the self-study research methodology is the inclusion of "critical friends" as part of the study. Critical friends provide constructive and honest feedback, provide a support system to the teacher-researcher, allow for new perspectives in the study, and their feedback can act as sources of critical data analysis in the study (Butler et al., 2011; Samaras, 2011; Samaras & Freese, 2006).

My first critical friend in this study is "Joan." Joan is a fourth-year teacher in the biology department at the high school where I work. Although Joan is a novice teacher, her recent training at the local university in the NGSS will help provide valuable critical feedback in this study. When I asked Joan (personal communication, January 2017) if she sees herself as more of a traditional teacher, more of an NGSS teacher, or somewhere in between, she said: “I’m more NGSS in accelerated biology and more traditional in non-accelerated biology. However, both courses see both teaching styles.” Joan sees herself as practicing “newer” teaching methods such as inquiry, problem-based learning, and flipping the classroom. I asked Joan how she envisioned herself teaching science in the next few years, and she declared: “I hope that my class is more than 75% NGSS-ified!” Joan also stated that to change her pedagogy; she would “like to change my follow-up with students’ initial models to explain scientific phenomena. I’d like to have students revise their initial models throughout a unit, or create a final model at the end of a unit.” Of the three members of the biology Professional Learning Community (PLC), Joan has the most contemporary ideas about education due to her recent training during undergraduate studies.

The second critical friend in this study, “Angela,” has been teaching for thirteen years. Angela previously taught at a rural high school for eleven years with a student body of 180-200 students where she was the only life science teacher. Angela’s autonomy as the only life science teacher allowed her more flexibility in experimenting with instructional styles than what she is experiencing at our much larger high school where she has been teaching for two years. When Angela was asked where she sees herself in the spectrum of teaching from traditional to the NGSS, Angela (personal communication, January 2017) stated that “I’ve been teaching with the phenomena based approach for years, especially when kids express a particular interest in exploring a topic in biology.” Angela sees herself somewhere in the middle of the teaching spectrum, but she said that it was not a consistent thing, and she makes choices about how she teaches “depending on the unit, the students, the ability of the students, the interest of the students, and the engagement of the students.” Angela’s years of experience in secondary biology education and her lack of formal training in the NGSS will provide a significant contrast to Joan's critical feedback. Critical friends research memos, both to and from my critical friends, will be used as a data source in this study that will help clarify mine, and my critical friend's perspectives, and interpretations of my research as suggested by Samaras (2011).

My critical friends will be given lesson data throughout the study as I complete the daily Science Lesson Evaluation: Field Notes Google Forms. Additionally, critical friends' conversations recorded during Professional Learning Community (PLC) meetings throughout the study will provide critical data that will highlight tensions and issues relating to implementing the NGSS at our high school which will be recorded electronically and coded. Both of my critical friends are members of the biology PLC team who meet collaboratively three times a week. Any discussions that take place during PLC time which focuses on the evaluation of my project's lessons will be recorded and transcribed for coding as a data source.

Additional Data Sources

Narratives are another acceptable data source in self-study research. A description of my educational life-history, as well as a description of my research process, will be included as data. According to Samaras (2011), a narrative can also include interpretations of visual data and discourse about the research process. Narratives of two class periods will be used as data sources in this study. A self-study class portrait will be presented using audio and video recordings of a traditional class period, and a student-centered class period.

One additional self-study data collection tool that Samaras suggests which will be used is the creation of concept maps. She suggests that concept maps are "visual displays that highlight connections and links of "big ideas" and document your understanding of a phenomenon by visualizing the relationships and complex ideas among concepts and the dynamics and connections between them" (Samaras, 2011, p. 174). As themes emerge during data analysis, a concept map will be constructed to help illustrate dominant themes.

Data Analysis

Data coding will be accomplished using traditional qualitative methods. An open coding process will be used for category generation and theme emergence. In this study, critical friend comments will be coded, and common themes will be discovered and analyzed. Coding is the process of discovering common themes through a thorough review of the data including student writings, interview transcripts, and field notes (Bogdan & Biklen, 2007). Simply put, coding is the process of sorting and organizing data. The qualitative coding process is well documented (Bogdan & Biklen, 2007; Krathwohl, 2009; Vogt, 2005), and begins by the researcher reading and listening to all the texts. It is important that the researcher develops a "storyline," which is the purpose of the study. The coding scheme will be based on the storyline.

The goal in coding is to identify and record frequent topics that occur that are critical to the research question. In the coding process, keycode definitions are made, then the coder determines which codes will be included, excluded, or are border examples per the storyline. Coding can be accomplished in several ways. In this study, different colored digital highlighters in Microsoft Word will be used to mark different ideas, concepts, and themes that emerge. Some of the codes in this study will be pre-set, or a priori, while other codes will emerge during the coding process. The coding scheme will also be refined as the data reveals the nature of information. For example, if there are too many instances of one code, the code should be broken down into subgroups to allow the codes to fit the data. After coding is complete, the codes will be categories in Microsoft Excel which will help in determining how the codes come together.

Trustworthiness

Trustworthiness in a research study is “the degree to which we can rely on the concepts, methods, and inferences of a study, or tradition of inquiry, as the basis for our own theorizing and empirical research” (Mishler, 1990, p. 419). Certain standards of trustworthiness must be realized in qualitative research. There are four different aspects of trustworthiness that have been identified to help achieve this realization (Lincoln & Guba, 1985). The first element of trustworthiness is the degree of confidence that others have in a research study’s findings. How relevant the study is to other contexts, and how consistent the results of the study would be if replicated are also important aspects of trustworthiness. Finally, the degree of researcher neutrality is considered in trustworthiness. In this study, trustworthiness will be attained through careful design, data collection, analysis, and reporting. Concerns have been expressed by those who question the trustworthiness of self-study that as a research methodology self-study may be invalid due to its perceived lack of vigor (2005). One way that trustworthiness in a research methodology such as self-study can be established is through the use of multiple and varied data sources which helps affirm and gives credibility to the researchers’ interpretations (Glense, 2006).

Self-study has gained recognition as a bona fide research genre in teacher research and education practice (Berry, 2014). Self-study research formalization was accomplished as the result of the formation of a special interest group of the American Education Research Association (AERA), the Self-Study of Teaching and Teacher Education Practices (S-STEP) in 1993. As a recognized research methodology, the emergence of self-study, while not without controversy, has contributed to its trustworthiness in educational research (Lassonde et al., 2009).

Data Triangulation

Triangulation of data is the idea that having many data sources in a study is superior to having just one source because multiple data sources can better lead to the phenomenon being investigated (Bogdan & Biklen, 2007). Bogdan and Biklen suggest to be transparent about different data-collecting techniques, such as official documents, observations, and interviewing, and to reveal if more than one researcher was involved in data collection (2007). Multiple data sources will be used in this study including video and audio recordings of instruction, field notes, student work, and critical friends' feedback.

Ethical Considerations

During this self-study, the full transparency of my project will be discussed with both university and school district leadership. Evidence of three-dimensional learning will be obtained through classroom video recordings and examination of student work. University Institutional Review Board (IRB) approval has been gained (Appendix H). This study, as it will occur during part of my daily life as a teacher, will ultimately improve student learning through changing my practice from a teacher-centered to student-centered pedagogy. There will be little to no risk to students during this self-study as it focused on my shift in instruction from a traditional methodology, to one that aligns with the three dimensions of the NGSS. A critical self-analysis of the conflict I experience as a traditional teacher shifting pedagogies will need to be openly and honestly assessed.

The identities of my critical friends will be protected, and aliases will be used. Both of my critical friends are current biology teachers at the high school where I am employed. My critical friends' contributions will contribute to the ethics of this study because, in self-study research, critical friends are a crucial component of ethical research review (Anderson, Herr, & Nihlen, 2007).

Design Limitations and Transferability

In self-study research, there are some notable limitations. First, because this research focuses on me as the teacher, and with the deep reflection of my practice, the sample size is clearly an issue. Secondly, while there are multiple data sources expected in this study, there is a possibility that the data may not be rich enough for robust theme analysis. Because self-study is a relatively new research methodology, there is a lack of research in my context and content area, secondary biology. Likewise, there is a gap in knowledge concerning how traditional secondary biology teachers shift pedagogically to the three dimensions of the NGSS in their classrooms, what that process looks like, and the tensions and issues that arise during such a curricular implementation.

In self-study practitioner research, issues of exaggeration and selective memory could come into play. Exaggeration is when a researcher makes events sound more or less significant than they occurred in the study, and selective memory is not remembering or remembering events selectively in the study (Price & Murnan, 2004). Telescoping and attribution could also become issues. Telescoping is where the researchers' ability to recall events is distorted with regards to when they happened, and attribution when a researcher takes credit for actual occurrences in the study but blames negative incidents on others (2004).

Transferability is the degree to which the study's findings can be generalized or transferred to other contexts, settings, or populations (Guba & Lincoln, 1981). In this study, the goal will be to produce qualitative data that will be transferable to other research in this field.

Study Assumptions and Challenges

Creswell's four philosophical assumptions for qualitative research will be the basis for this study (Carnaghan, 2013). They are:

1. Ontological (The nature of reality): Relates to the nature of reality and its characteristics. Researchers embrace the idea of multiple realities and report on these multiple realities by exploring multiple forms of evidence from different individuals' perspectives and experiences.
2. Epistemological (How researchers know what they know): Researchers try to get as close as possible to participants being studied. Subjective evidence is assembled based on individual views from research conducted in the field.
3. Axiological (The role of values in research): Researchers make their values known in the study and actively reports their values and biases as well as the value-laden nature of information gathered from the field.
4. Methodology (The methods used in the process of research): inductive, emerging and shaped by the researcher's experience in collecting and analyzing the data (2013, para. 4).

Challenges in this research study include the amount of time it will take to write or dictate field notes, video recording myself teaching, and transcribing and coding the data. Also, the nature of the feedback from my critical friends could impact me on a personal level, and what I discover about my practice may be disconfirming to my ideas of teacher efficacy.

Chapter 3 Summary

In this chapter, the research design of the study was first discussed, which was followed by the research questions in each phase of the study. In the next section, the study timeline, setting, and participants were described. Data sources and collection methods were identified followed by data analysis methods. Chapter 3 concludes with a discussion of study validity, reliability, ethical considerations in the study, the design limitations and transferability of the study, and the assumptions and challenges of the study. Next, In Chapter 4, data collected in the study will be presented and analyzed.

CHAPTER 4 RESULTS

The official adoption of the Next Generation Science Standards (NGSS) as the State of Illinois' science standards became law in February of 2014. The National Science Teachers Association (NSTA) position on the implementation of the NGSS strongly emphasizes that a considerable amount of effort will be required to make the conceptual shifts in instruction, curriculum, professional development, and teacher preparation needed to enact the NGSS (2013). The NSTA also calls for state and district policy makers to "allow ample time for teachers, educators, and administrators to carefully, deliberately, and reflectively participate in and carry out a process for planning and implementing the NGSS" (National Science Teachers Association, 2013, p. 1). In our local school district, this "ample time" has yielded only a series of meetings about science course sequence adjustments almost three years after the NGSS was to be implemented, leaving teachers such as myself to seek alternative methods to change their classroom instruction to align to the three-dimensional learning required by the NGSS. Thus, I chose self-study as a vehicle in my classroom to elicit pedagogical change.

In Chapter 4, the findings of the self-study are analyzed from the data that was collected methodically in my classroom. The results presented in this chapter are based on the collection of data obtained during phase I and phase II of the study. During the third cycle in this study, phase III, suggestions will be made for better aligning the Project Neuron unit to three-dimensional learning and the NGSS. The primary data collection source in this study is through field notes recorded while teaching a traditional science unit in phase I, and during the Project Neuron unit in phase II. The field notes are used as an in-depth reflective apparatus to evaluate my instruction during phase I and phase II. Field notes are written directly after each eighth-period biology class using the modified EQuIP Rubric. Field note observations are confirmed and cross-checked through the analysis of videotaping and digital recording of instruction. Additionally, data is collected while digitally recording discussions with my critical friends during biology Professional Learning Community (PLC) time. Student work is also analyzed to seek evidence of three-dimensional learning by students during each of the first two phases of the study.

The research questions in this self-study correspond to the three different phases of the study. However, the main research question in this study is:

> What issues arise when using self-study to guide my transition from teaching traditionally to teaching a unit that better aligns with the three dimensions of the NGSS?

Framework for Reporting Data

In this study, each of the three research phases has different data collection parameters. The data collected in each phase of the study is illustrated in Table 2.

Table 2

Framework for Reporting Data - Study Data Sources

Phase I – Before Enactment	Phase II – During Enactment	Phase III – After Enactment
DNA & cell division unit development and analysis Pre-analysis ecology part II unit EQuIP rubric Field notes ecology II unit video/audio recording Post-analysis ecology unit part II Self-study class portrait Self-study phase I concept map & tag clouds Self-study student work analysis Self-study critical friends reflections/validations qualitative analysis	Field notes Project NEURON unit. Video/audio recording Self-study student work analysis Self-study phase II concept map and tag clouds Self-study class portrait	Post-analysis Project NEURON unit

Table 2 Continued

Phase I – Before Enactment	Phase II – During Enactment	Phase III – After Enactment
Pre-analysis - Project NEURON unit EQuIP rubric Self-study education-related life history		

In following sections, data from each study phase are presented and analyzed through a variety of methods including an analysis of research field notes, EQuIP rubric analysis, concepts maps and tag clouds, critical friend reflections, student work, and through the self-study methods of class portrait and personal history.

Phase One – Before Enactment

The research questions for Phase I are:

1. What issues become evident when developing or selecting instructional units that more closely align to the three dimensions of the NGSS?
2. How closely do the characteristics of my practice align to three-dimensional learning when teaching biology traditionally?

The data collected in phase one of this study will be used to provide insight into how I teach, what I teach, and why I teach the way I do during a traditional science unit.

Self-Study: Planning Purposeful Pedagogies - Unit Design

According to the National Science Teachers Association's (NSTA) position statement on implementing the NGSS, "it is the task of states and/or districts to establish a curriculum and to develop and/or select instructional materials aligned with the *NGSS"* (2013, p. 1). Because there is currently a lack of high-quality instructional materials available that align to the NGSS, teachers find themselves searching for units and lessons because states and districts have been unable to provide aligned curricula. Teachers, including myself, find ourselves in the position of being the primary stakeholders in implementing the NGSS. The NSTA clearly warns against teachers taking this role by making its position clear that “the responsibility for implementation cannot and should not be vested solely in teachers and other school-based personnel” (2013, p. 1). Fortunately, the NSTA has released some guidelines for designing units and lessons that align to the NGSS (National Science Teachers Association, 2016b). The NSTA suggests using backward design incorporated in the BSCS 5E model. This same lesson planning model is utilized in the DNA and cell division unit, however, the NSTA suggestion is to brainstorm phenomena that are related to the disciplinary core idea that students are going to investigate. The process of designing instructional units that align to the NGSS using the BSCS 5E model is a highly complex endeavor as I discovered during the early stages of this study.

DNA and Cell Division Unit Development and Analysis

Developing the DNA and cell division unit was an attempt by myself as a practitioner to step into the role of an NGSS curriculum developer. Working with an expert in curriculum development at the local university, I spent the better part of a year researching “best practices” suggested in the *Framework* (National Research Council (U.S.). Committee on a Conceptual Framework for New K-12 Science Education Standards., 2012) and developing the unit. An outline of the DNA and cell division unit is shown in Appendix A. I gathered curricular resources such as *Argument-Driven Inquiry in Biology* (Sampson et al., 2014), *Biology Inquiries* (Shields, 2006), *Scientific Argumentation in Biology* (Sampson & Schleigh, 2013), and *Biology for NGSS* (Allan, 2014), which I felt contained the most current available NGSS “best practices” materials by which to model lessons within the unit. The unit I wrote covered biology course content required by our school district’s DNA and cell division Understanding by Design (UbD) unit outline (Appendix I). After several discussions with the university’s curriculum expert, we decided not to pilot the unit that I wrote due to several factors. First, we felt that the BSCS 5E lesson plan format (2014) was unwieldy in its layout and that it would be difficult for other biology teachers to navigate the lesson plans that I had written. Secondly, while the unit was robust in its blending of UBD and Disciplinary Core Idea (DCI) alignment, an analysis of the unit using the EQuIP rubric version 3.0 revealed some NGSS three-dimensional design deficiencies (Appendix D).

In category I of the EQuIP rubric lesson and unit evaluation tool, NGSS three-dimensional (3D) design was evaluated using three criteria. First, the unit was evaluated in part "A" as to whether the unit contains an explaining phenomenon or allows students to design solutions. The evaluation found that while this unit uses science and engineering practices (SEP's) that are NGSS aligned, the unit failed to combine the SEP's, crosscutting concepts (CCC's), and disciplinary core ideas (DCI's) into a coherent unit that has a story line or phenomena that unite the unit. Thus, students learn the DCI's in a disjointed manner that does not allow them to investigate DNA and cell division while integrating the three dimensions. The compartmentalization of this unit prevents students from engaging in real three-dimensional learning. While in some cases there are guiding questions within activities, there an absence of a guiding question that unites the whole unit. The evidence of quality for part A was rated "inadequate" due to these issues. My suggestions for improvement were to redesign the unit to embed a real-life scenario, problem, or phenomena that drives the unit. This redesign would better allow for three-dimensional learning, and enable students to design solutions to the problem or phenomena.

Section B of the EQuIP rubric provides a means to assess the integration of the three-dimensional elements of SEP's, CCC's, and DCI's. I found that the following SEP's were identified in the unit: asking questions and defining problems, developing and using models, engaging in argument from evidence, constructing explanations, and obtaining, evaluating, and communicating information. Additionally, the following DCI's were adequately covered in the unit: LS1.A, LS3.A, and LS3B. There was also evidence that the CCC's of patterns, cause and effect, scale, proportion, and quantity, systems and system models, and structure and function were found in the DNA and Cell Division Unit. Section B is given an "adequate" rating with the following suggestions for improvement. First, while the three-dimensions of the NGSS are represented adequately in this unit, they are not integrated throughout the unit in a cohesive manner. The unit is disjointed, and a redesign should be made to incorporate a guiding problem or phenomena to unify three-dimensional learning throughout the unit. With these changes, this unit may have the potential to become an NGSS aligned unit.

In part C of the EQuIP rubric unit evaluation, integration of the three dimensions is assessed. I commented that phenomena and/or problems are evident in this unit; however, they exist within each activity and not throughout the entire unit. Section C was given an "inadequate" rating with the suggestion that the unit should be redesigned with the help of the biology professional learning community (PLC), who could perhaps brainstorm a story line or phenomena that drive the unit.

The overall rating for category I: NGSS 3D design, is a one. This rating indicates that there was "adequate evidence to meet at least one criterion in the category, but insufficient evidence for at least one other criterion" ("EQuIP rubric for lessons & units: Science," 2016, p. 7). According to the EQuIP rubric, if the lesson rating is less than a two, the "review should stop and feedback should be provided to the lesson developer(s) to guide revisions" ("EQuIP rubric for lessons & units: Science," p. 7). Thus, the overall rating for the unit is an “N,” or not ready to review.

Being my first attempt at curriculum design, and not having formal university instruction in curriculum design, it is unfortunate that the DNA & cell division unit was rejected as not being aligned to three-dimensional learning, but I learned a great deal during the process. I became more familiar with the three-dimensions of the NGSS and the conceptual shift that would be required of teachers involved in transitioning their practice. It was at this point that I came to the realization that my identity as a traditional teacher was impacting my ability to shift to NGSS aligned pedagogy, and the decision to conduct a self-study to change my practice was undertaken.

Traditionally Taught Unit Enactment

Reflective practice has been used by researchers to closely examine, then problematize how they teach through reflecting on their own practice (Schon, 1983). The influence of reflective practice on self-study research enables teachers to reflect critically on their practice to help them develop and grow as they make sense of how they teach (Zeichner, 1999). In this study, the baseline is to critically analyze how I teach a traditional science unit. My definition of a traditional science unit is one that has not been aligned to the three-dimensions of the NGSS, and most importantly, does not contain a unit phenomenon or storyline. Through this analysis and honest reflection, I will gain a clearer understanding of my typical approach to teaching. Additionally, my self-identity as a teacher on the traditional side of the spectrum will be analyzed, along with reflections of how much of a shift in instructional methods will be required for me to transition into teaching a unit that better aligns with the three-dimensions.

Instructional Practices Pre-Analysis

It is important that I construct a definition of instructional practices that are perceived as being considered "traditional" or "NGSS aligned." Doing so will enable me to identify where I fall in the spectrum of traditional versus NGSS aligned instructional practices. Table 3 shows my conception of the differences between traditional teaching and NGSS aligned teaching practices.

Table 3

The Differences Between Traditional and NGSS Aligned Instructional Practices.

Traditional teaching practices	NGSS aligned teaching practices
Instruction is teacher-centered	Instruction is student-centered
Lecture is the primary instructional method	Cooperative student groups are the primary method of instruction
Teacher's role is the distribution of knowledge	Teacher supports, monitors, and engages students in learning
Teachers explain concepts to students	Students construct concepts through practices
Biological concepts are taught in isolation without a unifying phenomenon	Biological phenomena link learning to real-life problem solving
Students confirm their understanding of biological content through labs and assignments	Students discover aspects of biological content through three-dimensional learning
The classroom is regimented: It is quiet and orderly	Students work in groups that are active in vibrant discourse
There is an emphasis on assessment	There is an emphasis on understanding

In my self-analysis of where my practice falls in the spectrum of traditional versus NGSS aligned instructional practices, I place myself solidly on the traditional side of the spectrum. The main instructional method used in my classroom is through lecture or teacher-centered instruction. While students do occasionally work in groups on homework assignments, projects, or labs, those activities are designed to confirm my expert content knowledge that I have presented to the class as the content expert.

The climate in my classroom demands orderliness during instructional time, and I call on students to answer probing questions about their knowledge during presentations. I try to assume that some students have knowledge of some of the biology content, but I also assume that this is dependent on how good of a science teacher they have had in middle school.

I have included what I see as progressive instructional methods in my repertoire over the years that I have been teaching science. These methods include interactive animations that are integrated into lectures to help students visualize complex biological processes, and I incorporate formative assessments into my presentations using an audience response system (clickers) to provide immediate feedback for concept re-teaching. In my classroom, formative assessments are considered “practice,” and summative assessments determine the students’ course grade. I am highly concerned that my students understand the material because I believe that everyone should gain an understanding of biology. I realize that the focus is on myself as a teacher being the instrument by which their understanding is assured, and not by the students understanding the science of life through investigating natural phenomena. For purposes of clarity, any references made concerning me as a traditional teacher in the self-study will take these aspects of my teaching identity into consideration. Therefore, I consider myself to be solidly on the traditional side of the teaching spectrum.

The Traditional Unit

The current Understanding by Design (UbD) unit plan (Appendix J) for the ecology unit provided by my school district (*Ecology UbD*, 2013) calls for approximately eleven weeks of instructional time to complete the unit. Several years ago, an early attempt to align the unit to the NGSS was made where existing labs and activities were analyzed to see how they could be made to fit into the NGSS’ science and engineering practices, crosscutting concepts, and disciplinary core ideas. However, this attempt at alignment with the NGSS simply resulted in a reshuffling of the biology instructional units, including the separation of the ecology unit into parts I and II. The unit content within the freshman biology course was kept the same, and there was no effort to have teachers change instructional methods that better align to the NGSS, such as phenomenon based learning, unit storylines, or three-dimensional learning.

The traditional unit that was enacted and evaluated is part II of the ecology unit. For four weeks during the fall semester, I recorded field notes after my eighth period accelerated biology class to record how closely the unit aligns to the NGSS using the modified EQuIP rubric (Appendix K). My responses were written and automatically stored on Google drive. The classroom observations were also video and audio recorded using a GoPro Hero 4 digital video recorder, and an Olympus digital audio recorder. The audio recordings were transcribed using Dragon Naturally Speaking Premium 13, and any critical occurrences that were noted earlier, or that stood out during data transcription, were verified through the video recording. During enactment of the unit, student's work was also examined for evidence of three-dimensional learning, and audio recordings of critical friend conversations were made during our biology Professional Learning Community (PLC) time. In the following sections, the data collected during the traditionally taught unit is analyzed.

Pre-Analysis Ecology Part II EQuIP Rubric

A pre-analysis of the ecology part II unit was made before teaching the unit using the EQuIP rubric (Appendix K). In Category I: NGSS 3D Design of the EQuIP rubric, an evaluation is made as to whether "the lesson/unit is designed so that students make sense of phenomena and/or design solutions by engaging in student performances that integrate the three dimensions of the NGSS" ("EQuIP rubric for lessons & units: Science," 2016, p. 6). Part A of the assessment looks at specific evidence from materials and the reviewer's reasoning, and why this is considered as proof. In my evaluation response, I wrote that in the ecology II unit there is no real-life guiding problem or phenomena that drive student learning. This unit is predominantly teacher-centered as students passively receive knowledge directed by the teacher during lecture. The owl pellet dissection lab, the photosynthesis and respiration molecular modeling lab, and the properties of water lab are “cookie cutter” labs that confirm the content that was taught during lecture, and subsequently, do not allow students the opportunity to modify their understanding of a guiding problem or phenomena. My suggestions for improvement in section A is for a unit revision that includes a leading problem, storyline, or phenomenon that drives the unit. Other suggestions include incorporating owl predator and prey interactions and their niche in the ecosystem into the lesson and tying this into the owl pellet dissection.

In part B of category I, each dimension of three-dimensional learning is analyzed in the unit. In subsection “I,” my analysis revealed that the science practice of asking questions and developing and using models was found in the unit, but not in the context that is intended in by the NGSS. Students did construct original molecular models of the components of photosynthesis and reconstructed prey species, but there was not an opportunity for them to develop an initial model, and then to modify the model as their understanding of the model evolved during the unit. The evidence of quality for subsection “I,” was marked “inadequate.”

In subsection “ii,” I found that the NGSS DCI’s LS1.A and LS2.A, B, & C were covered adequately in the unit. The coverage of content is not surprising as this is a well-developed accelerated biology unit that has been taught and improved upon for many years. In subsection “iii,” my analysis found that the CCC’s of patterns, cause and effect, systems & systems models were found in the unit. The overall rating for section B was “inadequate” as all three dimensions must be rated at least “adequate” to give the section an overall “adequate” rating. My suggestions for improving three-dimensional integration in the unit include the realization that while the ecology II unit does cover the essential contents, and it did allow for the use of several of the CCC's, the deficit in this unit is in the underdevelopment of the SEP's. The unit should be examined closely, and revisions should be made to align with three-dimensional learning. Having a guiding unit problem that students solve, a story line, or a phenomenon, would provide the unit with a framework which would better achieve three-dimensional learning.

In part C of the EQuIP rubric evaluation, integration of the three dimensions is assessed. My evaluation found that 3D learning can only be accomplished through the interlacing of SEP's, CCC's, and DCI's together in the unit. This unit falls short in its teacher-centered design, and due to its lack of a guiding problem or phenomena. However, solid ecological content (DCI's) were introduced and covered in the unit as well as several science practices (although inadequately), were used in the unit. My suggestions for improvement in part C, three-dimensional integrations, include having the biology professional learning community (PLC) meet to redesign the unit. Either that, or by conducting a search for a high-quality NGSS unit that has been designed professionally to include an extensive three-dimensional learning design should be made, and the current unit should be scrapped.

The overall evaluation rating for category I: NGSS 3D design, for this unit is a "1," which indicates that "there is adequate evidence to meet at least one criterion in the category, but insufficient evidence for at least one other criterion," and that "the review should stop, and feedback should be provided to the lesson developer(s) to guide revisions" ("EQuIP rubric for lessons & units: Science," 2016, p. 7). The overall rating for the unit is an "N," meaning that the unit is not ready to review as it has not been designed for use with the NGSS. In the next section, the evaluation of the traditionally taught ecology II unit continues using data collected through field notes, observations, and critical friends feedback.

Traditionally Taught Unit Post Analysis

Field notes were written during phase I of this study using the modified EQuIP rubric. Field notes were written directly after my eighth period accelerated biology, the last class of the day when the events of the period were fresh in my mind. Video and audio recordings of the lessons were made as a backup of the events that occurred during the ecology II unit. Several sessions were omitted from data collection which included two testing days, and three review and makeup work days.

Observations During the Traditional Unit Enactment

In Phase I of this self-study, data was collected during twenty-three days of a traditionally taught ecology unit allowing me to make an honest assessment of how I currently teach secondary biology. Researchers have known for years that traditional teaching methods have consequences on student learning. One study found that while teacher-centered instruction allows students to perform well on assessments that measure the rote memorization of facts, quite often students do not retain the knowledge long-term because they have not learned to apply the knowledge (Lord, 1999). Other researchers discovered that lessons which are teacher-centered tend to be nonproductive, and can sometimes be a detrimental method of instruction, yet they continue to be the main way of teaching in both schools and colleges (Brophy, 1989; Caprio, 1994). In fact, other researchers found that the review of factual content by the teacher through lecture occurs over 90% of the time in many science classes (Angelo, 1991).

In the next section, I will analyze data collected during phase I of the self-study to answer the following research question:

> How closely do the characteristics of my practice align to three-dimensional learning when teaching biology traditionally?

I entered this study with the certainty that I fall solidly within the traditional teaching spectrum, but until now I have not had the opportunity to closely analyze how I teach to determine just how traditional my instructional methods are. An analysis of the twenty-three-day instructional period during phase I revealed that four different instructional methods were used during this period. Table 4 shows the breakdown of instructional days during phase I.

Table 4

Breakdown of Instructional Days During Phase I

Type of Instruction	Number of Days
Direct Instruction	7
Exam/Quiz	2
Review/Makeup	3
Lab/Research/Presentation	11

The ecology II unit had eleven lab and research days due to the owl pellet dissection, the molecular modeling lab, and the human impact project. I was surprised at the low number of direct instruction days during this unit. However, the direct instruction days were highly teacher-centered. The testing and review days were mostly teacher directed, except that one of the clicker review days was student run. Relinquishing control of the class to students on the clicker review day was an effort on my part to move my practice closer to a student-centered approach.

Lessons' anchoring phenomenon/problem. According to Maltese (2016), in a phenomenon driven science classroom, the learning is led by the students. Students are given questions, not the answers, which encourages richer engagement with the course content. In this way, students must actively figure out the core science ideas, instead of just passively learning about the content. Was there evidence of lesson or unit level phenomena in the ecology II unit? Table 5 lists the anchoring phenomenon or problem in each of the unit's lessons.

Table 5

Phase I - Lesson's Anchoring Phenomenon or Problem

Lesson	Lesson's Anchoring Phenomenon/Problem
Predator/Prey Interactions	What interactions do predator and prey species have?
Food Chains & Food Webs	Can a prey species be reconstructed to investigate a food chain? How are prey species identified after being consumed by a predator? How can a prey species be identified from examining its skeletal remains?
Photosynthesis & Respiration	How do plants take sunlight energy, carbon dioxide gas, and water and convert it into glucose sugar and oxygen?
Energy Use in and Ecosystem	How do organisms process carbohydrates during cellular reparation to extract usable energy for life function? What are the inputs and outputs (reactants and products) of cellular respiration?
Interactions in Ecosystems	What interactions occur between organisms in an ecosystem?
Energy Cycles in an Ecosystem	How does energy flow in ecosystems through the water, carbon and nitrogen cycles?
Human Impact	How do humans impact ecosystems?

Per Table 5, an anchoring phenomenon or question was present in each of the unit's lessons, but not as a continuing theme throughout the instructional unit, nor was the phenomenon or question consistently used throughout the lesson and subsequent formative and summative assignments. These results are not surprising as I learned secondary education methods in college during the era of objectives based teaching, and the focus on a phenomenon or guiding problem was not even acknowledged during that era of teacher training.

Traditional unit science practices. The inclusion of NGSS science practices was at a deficit during the ecology II unit. Five of the lessons had no observable science practices integrated with the content. Two of the lessons used the science practice of planning and carrying out investigations, one lesson was evaluated as using the science practice *of* asking questions, seven lessons were evaluated as using the developing and using models science practice, and during five lessons, the science practice of obtaining, evaluating, and communicating information was used as is illustrated in Figure 1.

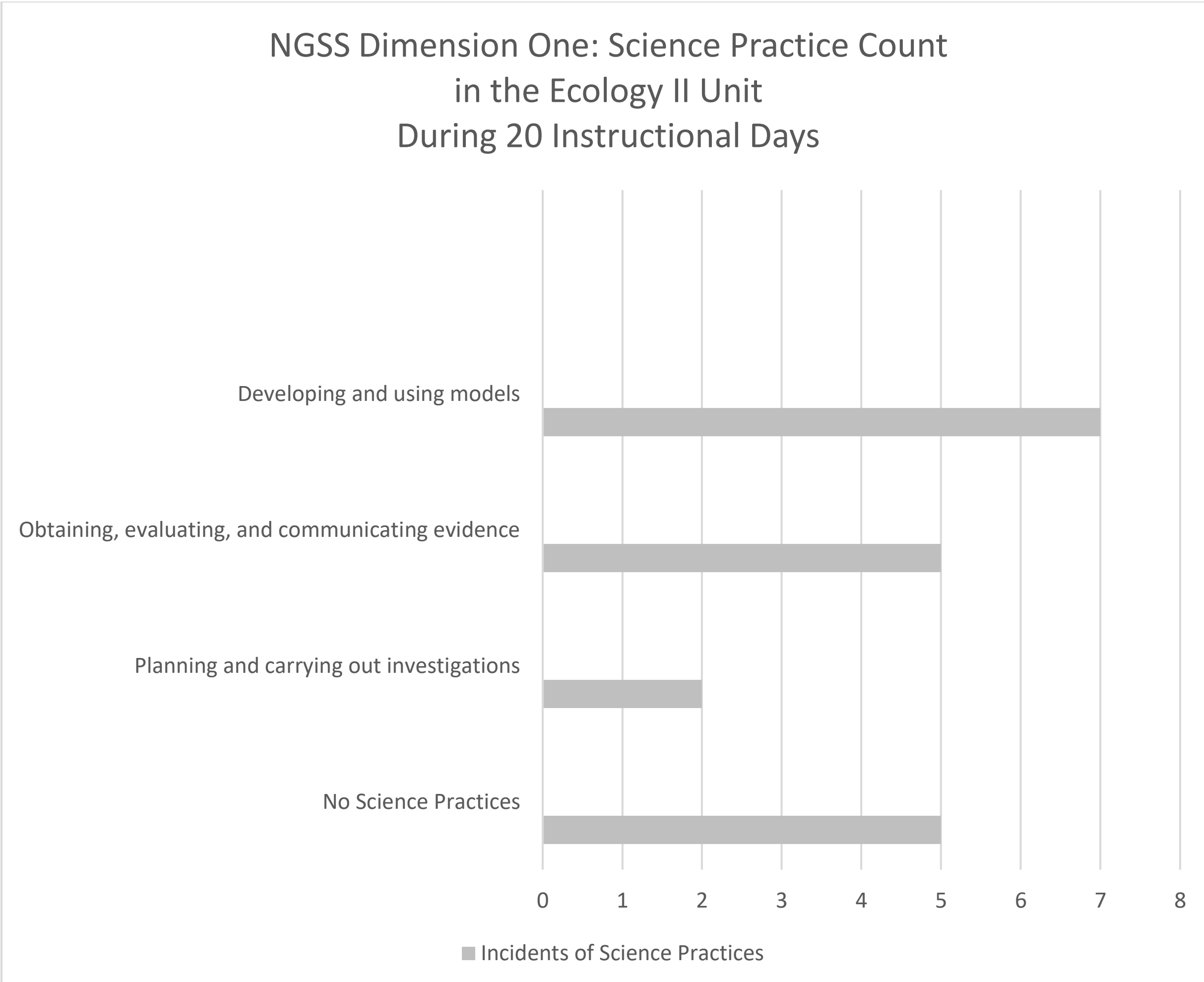

Figure 1. Science practices in the Ecology II Unit. A count of the number of incidents of science practices in the traditionally taught unit.

During my evaluations of the ecology II lessons, it was often a struggle to decide which science practice applied to most of the lessons, or if the lessons contained the NGSS science practices at all. I feel that I was hesitant to assign a science practice to some of the lessons, as my understanding of the actual application of these practices is still evolving since commencing this study. For example, it may be argued that student reconstruction of predator species through owl pellet dissection could be considered model construction. In modeling instruction, a model is a conceptual representation of a real thing's structure, and mental models are a representation of a corresponding representative structure, both of which can be developed by students as mental tools to make better sense of a physical reality, which allows them to answer questions and make predictions (Hestenes, 1987; Johnson-Laird, 1996).

Students are often asked to draw or describe a model of the phenomenon prior to investigating it in modeling instruction, but that did not occur in during the owl pellet dissection lab, or during the photosynthesis and respiration molecular modeling lab. According to *A Framework for K-12 Science Education* (2012), “Modeling is also a tool that students can use in gauging their own knowledge and clarifying their questions about a system. Student-developed models may reveal problems or progress in their conceptions of the system, just as scientists’ models do” (2012, p. 94). If students are not asked to devise their own models of a system, then the opportunity will be lost for them to revise their model as their conception of the system’s changes.

Another noticeable deficit in science practices during the ecology II unit was the absence of the science practices of analyzing and interpreting data, using mathematics and computational thinking, and engaging in argument from evidence. While these science practices are identifiable during some of the other units taught during the introductory biology course, I feel that their absence represents a gap in this unit.

The traditional unit crosscutting concepts. In the analysis of the use of crosscutting concepts during the ecology II unit, I found that only four of the seven CCC’s were present as is shown in Figure 2.

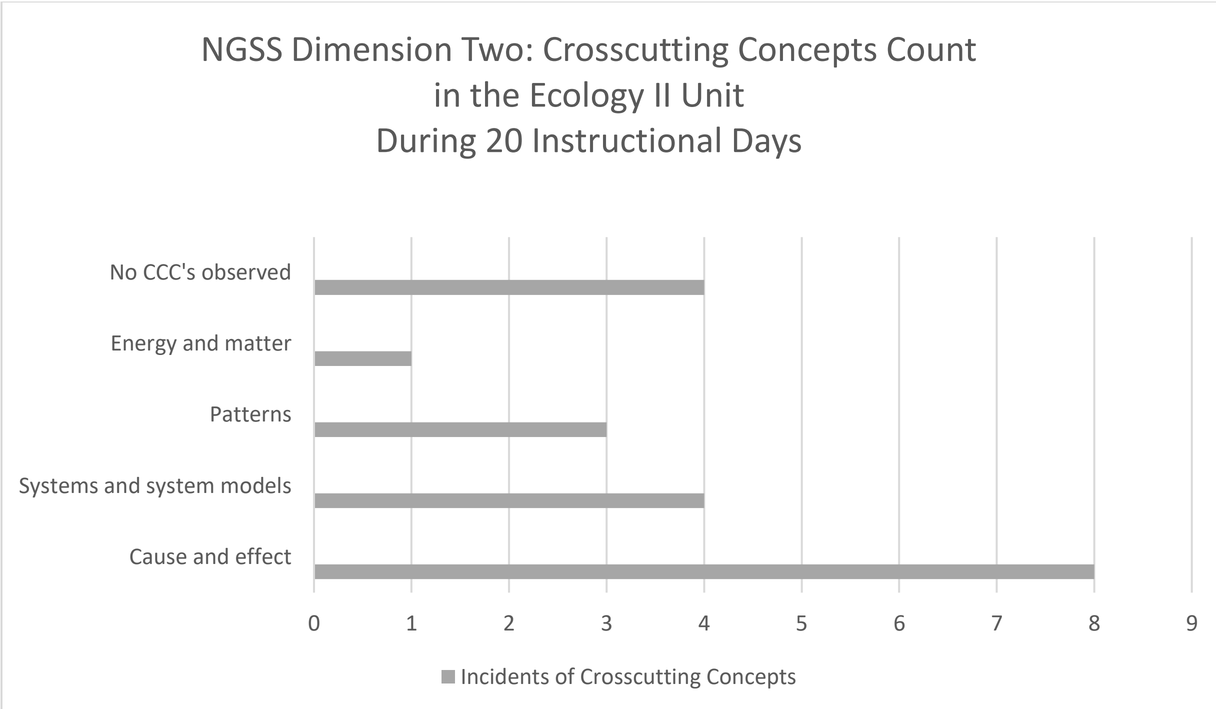

Figure 2. The crosscutting concepts in the ecology II unit. A count of the number of incidences of crosscutting concepts in the traditionally taught unit.

The prevalent crosscutting concept used during the ecology II unit was cause and effect, which was the focus when students investigated and proposed solutions during the Public Service Announcement (PSA) project. I also found that *s*ystems and system models, and patterns were concepts used during the molecular modeling lab, and during the owl pellet dissection. Finally, energy and matter were concepts used during the energy use portion of the unit, as well as during the discussions we had as a class concerning food chains and food webs, and during the owl pellet dissection lab. However, I am conflicted as to whether the crosscutting concepts that I have identified in the lesson truly reflect what the NGSS intends according to the NGSS' description of three-dimensional learning (2013). The description states that "the Framework emphasizes that these concepts need to be made explicit for students because they provide an organizational schema for interrelating knowledge from various science fields into a coherent and scientifically based view of the world" (para. 4). I believe that students should be made aware of the crosscutting concepts that are used during instruction so that they can better understand how they integrate with the disciplinary core ideas and science practices.

Traditional unit disciplinary core ideas and performance expectations. The unit DCI's were easily identifiable. In my analysis, I found that the ecology II unit as presented in the accelerated biology course presents 10 instances of DCI LS2.B: Cycles of matter and energy transfer in ecosystems. There are four cases of DCI LS1.C: Organization for matter and energy flow in organisms, and six cases of DCI LS4.D: Biodiversity and humans, which is indicated in Figure 3.

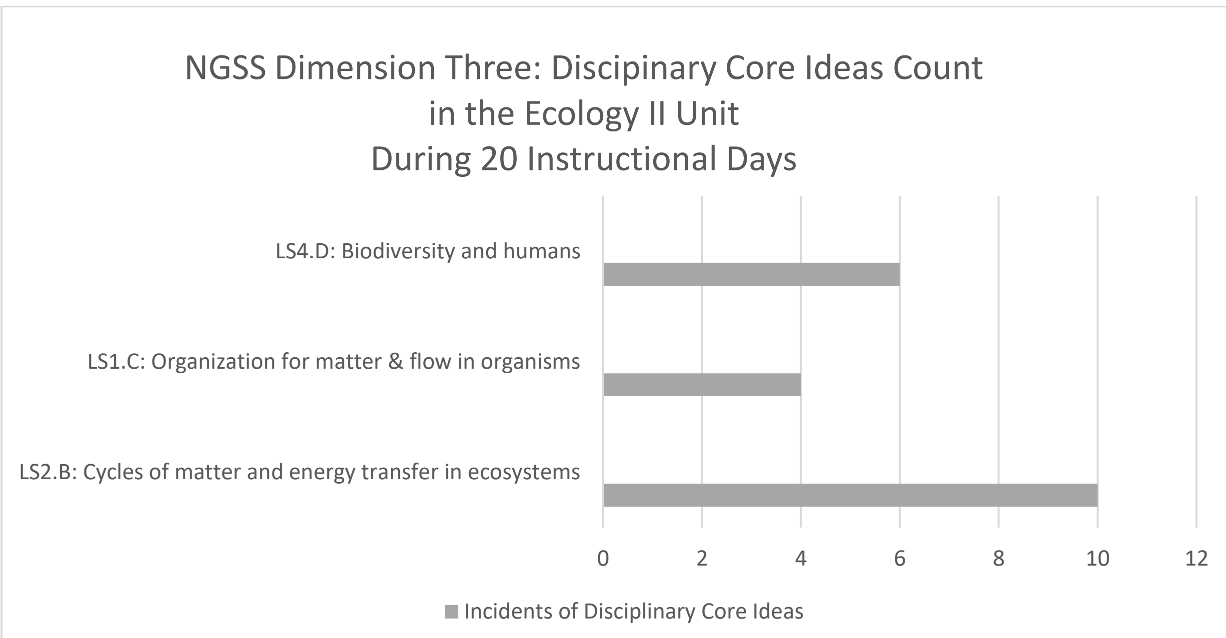

Figure 3. Disciplinary core ideas in the Ecology II Unit. A count of the number of disciplinary core ideas identified in the traditionally taught unit.

The ease at which I could match the disciplinary core ideas to the ecology II unit was surprising. The 15-life science DCI's are broad enough to encompass most of what I teach traditionally with a couple of exceptions. The units on microbiology and protists, plants, and animals are not emphasized in the DCI's. The NGSS alignment difficulty in this unit arose with the analysis of the unit's performance expectations as is shown in Figure 4.

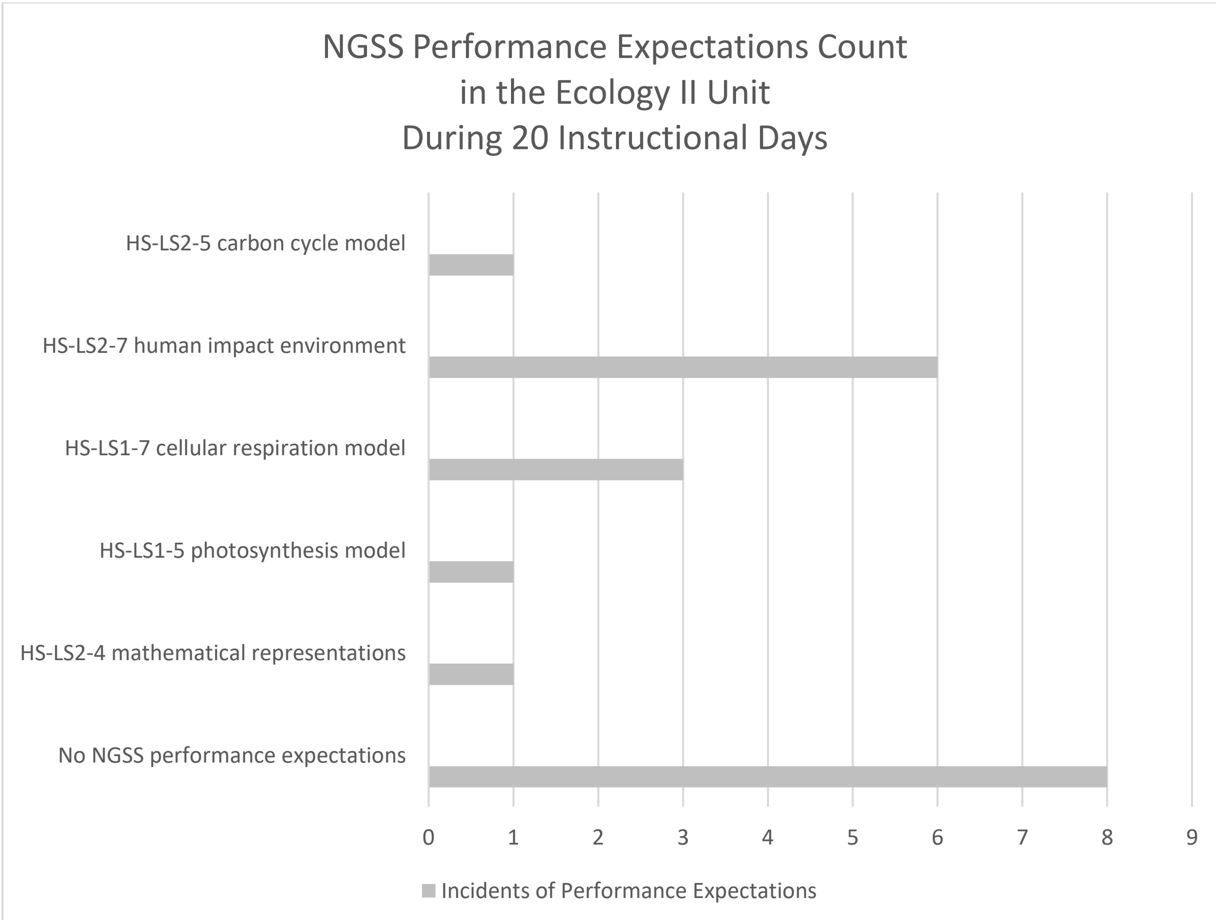

Figure 4. Performance expectations in the Ecology II Unit. A count of the performance expectations in the traditionally taught unit.

The NGSS performance expectations (PE's) seem very explicit in their focus, and thus, I found it difficult to align some of the lessons and activities in the unit to specific performance expectations. This unalignment is evident in eight of the twenty observed days not being assigned a PE. Thirty percent of the lessons in this unit were identified with HS-LS2-7: Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity, which was a direct reflection of the human impact public service announcement project. Three of the lessons fell under HS-LS1-7: Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken, and the bonds in new compounds are formed resulting in a net transfer of energy, which corresponds to the photosynthesis and cellular respiration lesson and labs.

Performance expectation HS-LS1-5: Use a model to illustrate how Photosynthesis transforms light energy into stored chemical energy, was identified with the molecular modeling lab, although this use of modeling in the strictest sense is questionable as students did not originally develop their own mental models and revise them during the lab. Performance expectation HS-LS2-4: Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem, was evident in the food chain and food web homework assignment where students had to calculate rates of energy flow in ecosystems. Finally, performance expectation HS-LS2-5: Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere, was partially covered in the lesson and homework assignment on the carbon cycle. In phase I of this study, one of the research questions asked:

> How closely do the characteristics of my practice align to three-dimensional learning when teaching biology traditionally?

Through an analysis of field notes recorded during this unit, I came to several conclusions which will help me answer this research question. First, my more traditional teaching methods obviously do not align with the three-dimensional instructional model suggested by the NGSS. I knew this is going into this self-study. However, I did discover that my teaching did have some components of three-dimensional learning that I did not anticipate, moving this more traditional unit further down the spectrum towards NGSS alignment than I originally believed. First, some of the disciplinary core ideas and performance expectations found in the NGSS did fit within the ecology II unit. I originally expected minimal correlation between a traditionally taught unit and three-dimensional learning. Coming to the realization that teaching a secondary accelerated biology class has similar content as what the authors of the NGSS expect was disconfirming. Also, some science practices and crosscutting concepts were identified in the traditional unit, which was also surprising to me. The greatest amount of self-realization occurred in the discovery of just how far the ecology unit was from the intentions of the NGSS, and how this distance was due to the lack of a common phenomenon throughout the unit, as well as a lack of a storyline. To me, this realization was significant as it represented a major shift in how I view the design of a well-structured science unit. Also, I came to the realization that I have been following the same well-established teaching routines for many years, as is illustrated in the self-study class portrait.

In the next section, a self-study class portrait of one of the direct instruction days in this study will be presented to provide a clearer view of what the structure of a typical teacher-centered class period should look like.

Self-Study Class Portrait

Self-study provides a variety of methods that allow practitioners to analyze their teaching. According to Samaras (2011), creating a class portrait provides “a visual representation of your current classroom situation and your practice capturing the academic, social, and cultural theater of your context, and the interactions of learning” (p. 13). Samaras also claims that this activity allows for critical reflection of classroom dynamics which helps the teacher to identify the proposed change and the planned pedagogies. In this section, the class portrait self-study method will be used to analyze the occurrences during one of my traditionally taught class periods. The following narrative is a description of a typical classroom teaching episode during this unit. Labs and other activities during this unit do not follow this format.

Before students show up to my class, I have the attendance book and seating chart placed on a rolling multimedia cart at the front of my classroom by the Smart Board. There is a bin at the front of the classroom where students turn in their work upon entering the classroom. Several students who were absent the previous day approached me for the work they missed, and I hand them the papers as they approach me. As students file into the classroom, I greet them by name and make some small talk. Students have assigned seats, and they are all seated as the bell rings for the period to begin so that they are not marked “unexcused tardy.”

Students are sitting in rows of two desks, three desks, and three desks. This arrangement makes it easier for me to move around the classroom and to move students to different seats if they are too talkative. There are thirty desks in the classroom and seven lab stations. The classroom is set up in three sections; the teacher area is at the front, the center instructional section is in the middle, and the rear lab section contains sinks and gas outlets.

The 8th hour accelerated biology is made up of a very ethnically diverse group of students. There are students of African American, Indian, Vietnamese, Chinese, Korean, and Caucasian ancestry. After taking attendance and entering it into a laptop computer, I welcome my students to biology class and immediately point to the whiteboard at the front of the room where the plan for the week is written. Today is Monday, so I go over the plan for the week with my students. Students have the last of seven vocabulary quizzes of the semester today, and I ask them to spread out to their preassigned quiz areas. Students quietly work on their quizzes while I walk around the classroom to monitor their progress. Within ten minutes, students start finishing up the quiz, and I ask one of them to collect the quizzes as the other students finish. Once everyone is finished, I discuss how little time there is left in the semester as we are in the month of December, and I ask a student to go to the class calendar at the back of the classroom to show the other students just how little time there is left until final exams.

Students now have their notes and writing utensils out, and I direct their attention to the Smart Board where I begin the lecture for today in the ecology II unit. As I go over the PowerPoint slides, I ask the students questions about the concepts they are learning. Several students raise their hands to answer the questions, and I try to randomly pick a student out to answer the questions. This questioning technique is what I was taught in college and during student teaching, and one I emphasize when I train student teachers. It is based on research that shows instruction without questioning is less effective than instruction with questioning (Marzano, Pickering, & Pollock, 2001). In the NGSS, asking questions and defining problems is one of the science practices, but the focus is on students asking questions to solve problems, and not the teacher eliciting students' content knowledge (NGSS Lead States, 2013).

The class is quiet and orderly. I show a two-minute ecology video clip that corresponds to the topic I am covering. Once again, it is the typical students who quickly raise their hands to answer questions, mostly boys, as the shyer students quietly listen. The power point slides include pictures and illustrations that I have inserted to help students visualize the content. Students raise their hands to answer questions as we go through more PowerPoint slides. I try to use anecdotes and real-life examples as I present the information.

My position during the entire lecture is at the front of the classroom in my "teaching spot." I move minimally around the classroom during instruction. I use hand gestures when I am explaining concepts. The lecture continues until I complete the number of slides I want to go through, and I wrap up with a short review of what I have just taught, and what they should have learned. I ask a student to hand out the homework, and I give students permission to work together in groups at the lab stations on their homework assignments for the last ten minutes of class. During this time, I answer a couple of questions that groups have about the homework. The bell rings and students leave the classroom.

Teaching Assumptions

The class portrait that I have just described is characteristic of the way I have been teaching secondary biology for over two decades. Variances in my routine include test and quiz reviews, and lab activities. I feel comfortable, relaxed, and in control teaching within my well-established routine. This way of instruction represents a teaching style on the traditional side of the spectrum. Students verify the information that I have taught them through a variety of labs and activities, and that is characteristic of what occurs in a teacher-centered classroom. The assumptions that I have about teaching science that contribute to my traditional instructional approach are presented in Table 6.

Table 6

Teaching Assumptions Which Contribute to My Traditional Instructional Approach

Assumptions About Teaching
Students are in school to learn
Education is the key to being successful in life
Students should become lifelong science learners
Organized classrooms promote student engagement
Students learn best when I teach them the material
Lecture assures that all students learn the same material
Lectures provide a controlled learning environment
Students should be engaged in the learning process
My class should be challenging
Classrooms should be safe spaces free from learning distractions
There are essential biological concepts that students should learn in high school
Students should not disrupt the learning of other students
Students should learn lab skills in science classes
Teachers should develop relationships with students
Students should have a voice in the classroom

The teaching assumptions in Table 6 show an emphasis of the teacher being in control of the classroom. Having attended boarding school in my youth, and having a military background, have both influenced my militaristic discipline based classroom structure. Both institutions require personal discipline in a controlled environment, and those traits have been transferred into my classroom organizational and discipline structure. Also in my assumptions about teaching are issues related to my desire for students to be successful learning science. Over several decades, I have taught students who have gone on to study biology at prestigious institutions such as MIT, Princeton, and Brown. Several students have kept in contact with me, and have expressed their appreciation for being challenged intellectually in freshman biology class. They claim to have a sound basis in biology when they entered college. Comments such as these have reinforced my perception that the methods I use to teach my classes are successful. If this is the case, then why change my practice?

My preferred teacher-centered instructional approach has been through lecture. During a lecture, I can assure that students receive the same material through a homogeneous process in a controlled learning environment. From my perspective as a more traditional teacher, lectures allow me to control the content that is taught and monitor student behavior simultaneously. This contrasts to student-centered learning where I assume that I am unable to assure that students are learning the required content, and I may lose close control of the learning environment. However, the benefits of a student-centered learning environment are well documented (Franzen et al., 2007; Krajcik & Merritt, 2012; Lord, 1999; McParland et al., 2004). I contend that I should be able to maintain many of my core instructional assumptions while shifting my classroom to a more student-centered learning environment, while discarding others. By doing so, my students can better learn how to think like scientists.

Self-Study Phase I Concept Map and Tag Clouds

During the analysis of field note data collected during phase I of this self-study, a concept map, and tag clouds were created to help visualize aspects of instructional methods, general reflective comments, points of tension, and issues of control.

Phase I concept map. In self-study research, a visual tool that can be helpful in understanding the data is a concept map (Samaras, 2011). Concept mapping allows for the visualization of the relationships between different concepts and lets us understand how the human mind understands various themes (Wheeldon & Faubert, 2009). In this study, a simple concept map is used to demonstrate the relationship between myself as the teacher, and the various aspects of traditional teaching during a typical class period as was presented in the self-study class portrait. In phase II of the study, a similar concept map will be constructed to help visualize the relationship between myself and the various aspects of teaching during the Project NEURON unit enactment as means of comparison.

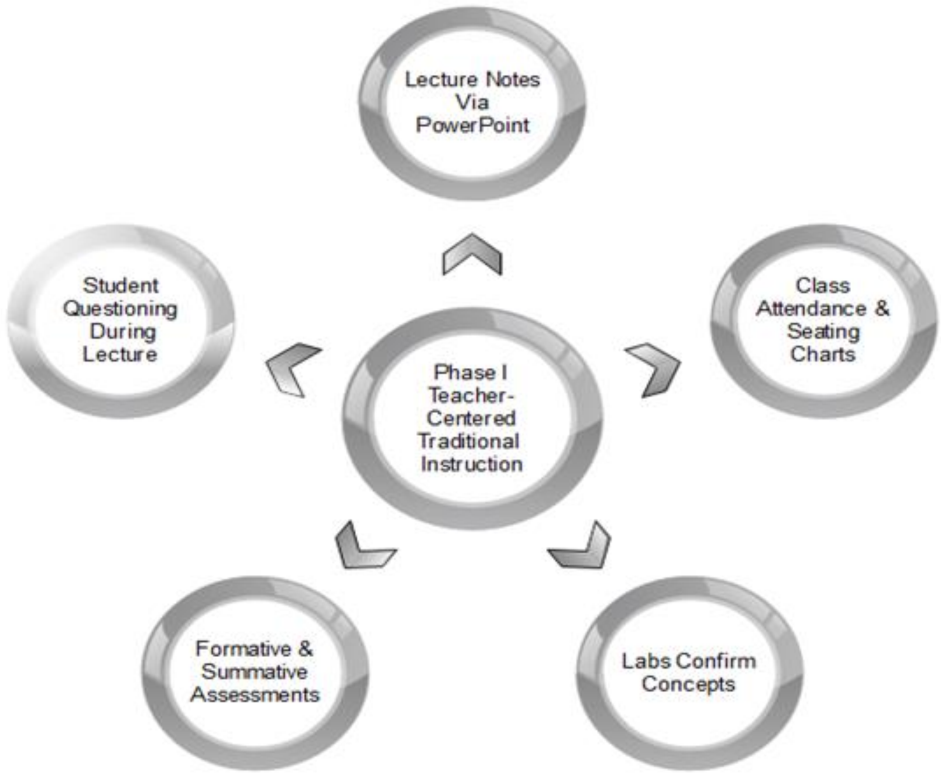

Figure 5. Concept map of phase I traditional teaching relationships with the teacher at the center and all aspects of teaching and learning radiating outward.

The concept map in Figure 5 illustrates the teacher-centeredness of traditional instruction in my classroom. All aspects of learning are directed by myself as the teacher including the arrangement of desks and the strategic placement of students to minimize discourse and interruptions during instruction. During lectures, the one-way dissemination of information is provided through PowerPoint presentations, but while student questioning does occur during lectures, those who respond are chosen by the teacher, and they are usually the same handful of students who are more outgoing than others. The selection of both formative and summative assessment questions is teacher selected, and students have little say in differentiating how they are assessed. Finally, the “practice” part of traditional science teaching relies on the confirmation of concepts taught during instruction, and not on solving problems or designing novel solutions.

Phase I tag clouds. Another method of visualizing data in qualitative research can be made through tag clouds which highlight the frequency of word usage in discourse. Recently, tag or word clouds have started to be used in both research and education as a method to analyze data that is textual in nature (Gill & Griffin, 2010). Tag clouds allow the reader to see how common words in the text are emphasized per their frequency. As a result, tag clouds “reflect individual associations with resources and are based on the specific meaning or relevance to the respective user,” and tag clouds can be used to “capture collective knowledge” (Cress & Held, 2012, p. 237). One of the aspects of tag clouds that make them so appealing is that the “leanings and meanings” in the documents that are analyzed become abundantly clear very quickly (Gill & Griffin, 2010). The tag clouds were generated using Tagul.com, a free word cloud website. In the first tag cloud, all the words in the general field note observations written during phase I were entered in the Tagul program, and common words were excluded from the analysis as is shown in Figure 6.

Figure 6. Tag cloud of phase I field notes general reflective comments

An analysis of the tag cloud word repetitions in the field notes general reflective comments reveals an emphasis on the student as the predominantly used term. My reflections focused on pedagogical aspects of the ecology unit such as the lessons, labs, rubrics, assessments, and video. Other reflections in my field notes reveal an emphasis on NGSS related aspects during the traditional unit including phenomena, EQuIP rubric, curriculum, research, pilot, models, and PLC's.

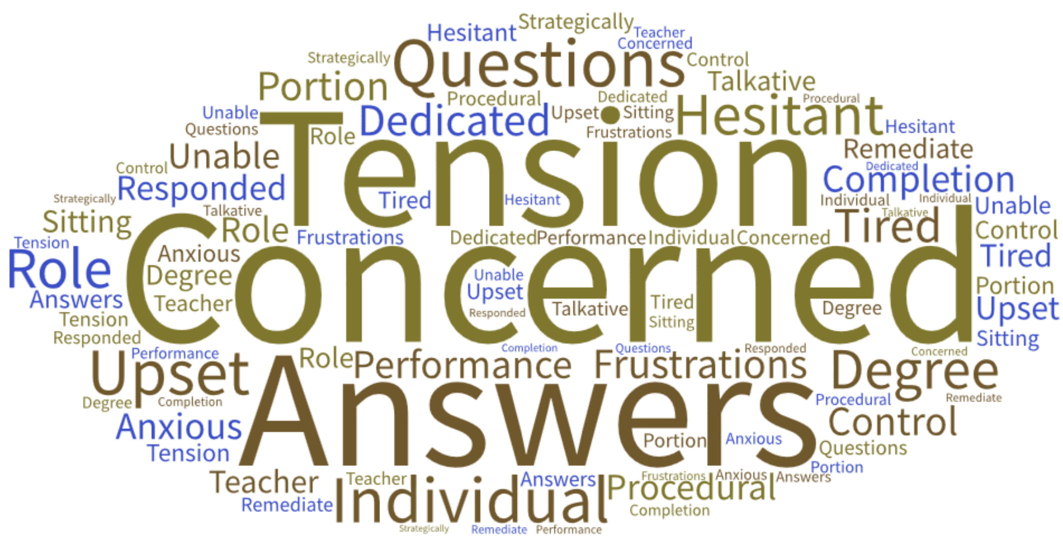

Figure 7. Tag cloud of phase I field notes points of tension and issues of control

Words written in field notes reflections made during phase I, concerning points of tension and issues of control, were entered in the tag cloud generator, and the results are displayed in Figure 7. The word usage concentrations show an emphasis on the dominant themes relating to the future implementation of the NGSS. Some of the dominant themes that emerged using tag cloud analysis were issues of tension I felt when considering the future implementation of the NGSS in our school district, along with issues surrounding frustrations I felt about relinquishing my control of the classroom in the upcoming transition. Using the modified EQuIP rubric to evaluate a traditional science unit provided a user-friendly platform that helped me to reflect on and record issues of NGSS alignment in my field notes.

Self-Study Education-Related Life History

In self-study research, multiple methods allow the researcher to take a critical look at their practice. One of these methods is through recounting education-related life histories. This research method allows the practitioner to reflect on aspects of their learning that may have implications in their research question and interests (Samaras, 2011). Researchers believe that this method is a very useful way for teachers to reflect on their identity, on the goals and values they bring into the classroom, and to "develop and awareness of your development as a teacher and what current beliefs and values you bring into your practice" (p. 95). In this section, I will reflect on several episodes in my life that I believe helped me develop into the teacher and researcher that I am today and the realization that I fall on the traditional spectrum as a science teacher.

My life as a young child was transitory, as my father was a corporate executive who had accepted a position in the French Alps. I found myself in a Swiss boarding school at the age of eleven, a profound change from my life growing up in Middle America. Our days in boarding school were spent in engaging classes with a diverse group of students, and exceptional, international teachers. During the evening, we were ushered into the library in our slippers and sports jackets after dinner for study hall. The study hall monitor from New Zealand would supervise us with military-like discipline. Students had no choice but to be on task. The study hall monitor carried a stick.

Study hall became a place that for two hours each night I could focus on finishing my homework quickly and accurately in hopes that there would be time left to roam the stacks and pursue my interests. I believe that it was during this guaranteed, highly disciplined time in my young life that I first became a researcher. I would explore atlases, browse encyclopedias, and let one topic lead me into another. My life was changed by the skills that I developed during the years I spent during study hall in Swiss boarding school. This disciplined study time that I experienced early in life provided an experience that otherwise would not have been available to me in another educational situation. I believe that this experience helped shape my ideas and assumptions about education that would later be reflected in my secondary classroom.

Later in life, I found myself in a six-year enlistment in the United States Navy. As a night shift supervisor for an aviation electronics shop on an aircraft carrier, I had lots of responsibility. The success of a mission depended on the perfect functioning of our squadron's F-14 Tomcats. We spent our nights in the shop troubleshooting electronics systems in twelve fighter aircraft. On one occasion, the identification friend or foe systems suddenly began acting up on many of our jets. Over the next two days, our shop was under a great deal of pressure to solve the problem or else the squadron would be grounded.

Together, my team brainstormed ideas. We looked at all the electronics schematics and ruled out many possible causes. Then we solved the problem. The identification friend or foe coding gun had a malfunction in the pin alignment. While conducting a close examination of the coding gun, one of the possible culprits, we just happened to notice a very slight bend to the main lever arm. This slight bend was causing the computer to read part of the code improperly. I look back at this incident as the time in my life when I became a problem solver. The problem-solving skills I learned in the United States Navy have helped me become the teacher and researcher that I am today. The discipline that I experienced in the armed forces, coupled with the discipline that I experienced in Swiss boarding school, further shaped the type of teacher that

I would become. The influence of these life experiences provided a framework for my later development as a teacher who exerts lots of control and structure in my classroom.

My college training as a secondary science teacher occurred during the era of objectives and transitions. First, we were taught to take attendance quickly, and then after our objectives were neatly written on the board, we were to state them clearly to the class. We were taught that the objectives were the key to the lesson and that students could not learn without them. The biology textbook was the roadmap that we followed to guide instruction. The book was to be used to outline the biology lesson, and the questions throughout the chapter were the formative assessments. The chapter test questions were provided in a supplemental publication. During my first several years teaching high school science, I used textbook chapter assignments and tests as assessment sources, and the content in the textbook became the content that I taught. However, like most teachers, I became unsatisfied, and I was always looking for a better way to get the message across. I found myself modifying and adding biology content, and I began developing my assessment tools over the years.

In the early days, I would outline the lesson on the board following the book, and hand writes the notes on the overhead projector. I would make clear, concise notes in permanent marker so that they could be used year after year. My chalkboard became the tool for visualizing challenging biology concepts like photosynthesis and cellular respiration. I became and expert at drawing diagrams on the board with colored chalk.

In the early 2000’s when multimedia projectors became available, the rush was on to convert our handwritten overhead notes into Microsoft PowerPoint. My co-teacher and I solicited funds from various donors, and we purchased a LED projector for our classroom. It was the first classroom projector in the school. My electronics background in the United States

Navy ensured that the best available computer was built at my cost for my classroom. Over time, the multimedia presentations I developed became rich with animations of biological processes, embedded videos, and manipulative flash animations.

By the end of the decade, audience response systems, or "clickers," became available. I spotted four sets of them in my building principal's office, and I talked him out of a set for my classroom. My presentations now included technologically enhanced formative assessments. My lectures went something like this: students would learn a concept while we went through the lecture notes. These were the same notes that had evolved from the 1990's overhead versions, and clicker assessments were integrated throughout the lessons. I taught, students responded, and I retaught if a concept scored poorly on the clicker assessment. Armed with binders of labs, activities, and assignments that I had developed, I thought I was set, until the NGSS made its appearance.

At first, it was hard to comprehend the paradigm shift that the NGSS required. Many discussions occurred between myself and my colleagues trying to decipher the complexities of the NGSS. Three-dimensional learning did not make sense to the science teachers in my department, and we had many discussions trying to rationalize what was being asked of us. I finally came to the sobering realization that as my teaching was more on the traditional spectrum, a profound change would need to occur both in my pedagogy and my mindset to elicit the changes that I would need to make as a practitioner. The idea of student-centered instruction contrasted to the orderly, teacher-centered classroom climate that I had spent so many years fostering. I assumed that my role would be diminished under the NGSS as I gave more control to the students, and all the work that I had completed over the last several decades developing a biology curriculum would need to be tossed out so it could be replaced by a curriculum that I was unsure of.

Self-Study Student Work

It has been made clear that I am a science teacher attempting to change my practice by undergoing a detailed and reflective analysis of my practice via self-study. Although glimpses of each of the three dimensions of the NGSS could be identified separately in the traditional ecology II unit, no instances of all three dimensions coming together cohesively have so far been identified. However, I believe that the best chance of identifying three-dimensional learning could be made by examining student work in the traditional unit. According to the definition of three-dimensional learning found in the Next Generation Science Standards, "lessons and units aligned to the standards should be three-dimensional; that is, they should allow students to actively engage with the practices and apply the crosscutting concepts to deepen their understanding of core ideas across science disciplines" (2013, para. 1).

When examining student work for evidence of three-dimensional learning, it is important to identify some of the characteristics of three-dimensional learning that should be evident in the example. Table 7 lists some of the characteristics of three-dimensional learning.

Table 7

Characteristics of Three-Dimensional Learning

Characteristics of three-dimensional learning
Three-dimensional learning involves making sense of phenomena
The three-dimensions working together allow students to design solutions to problems
Three-dimensional learning should mirror what real science is like
The three-dimensions should be grade appropriate
Three-dimensional learning is a process, not an isolated instance

The characteristics of three-dimensional learning that are described in Table 7 show that three-dimensional learning involves combining the dimensions together through the *process* of science, and not just as an isolated incident. This idea is confirmed by researchers who describe how three-dimensional learning "shifts the focus of the science classrooms to environments where students use disciplinary core ideas, crosscutting concepts with scientific practices to explore, examine, and explain how and why phenomena occur and to design solutions to problems" (Krajcik, 2016, para. 2). These actions reflect science practices that should be inherent in examples of three-dimensional learning.

One resource that is available to our biology PLC is "POGIL" activities for high school biology (*POGIL activities for high school biology*, 2012). Process-Oriented Guided-Inquiry Learning (POGIL) assignments are student-centered, guided-inquiry based instruction activities that help students to "construct new understandings while they simultaneously develop key process skills, including critical thinking, problem-solving, and collaboration" (*POGIL activities for high school biology*, 2012, p. v). All teachers in the biology PLC use POGIL assignments interspersed throughout the biology units that they teach. I valued the increased difficulty level of the questions that were posed to students in the POGIL activities, many of which require the analysis of models, as they were an improvement over most homework assignments I have used in the past that relied on the rote recollection of facts. The examples of student work represented in this section are all from POGIL assignments given during the ecology II unit. The examples will be evaluated for evidence of three-dimensional learning.

Model creation. In this example, students are asked to apply their understanding of food chains and cycles of matter in ecosystems to create a model of a human food chain and answer extension questions.

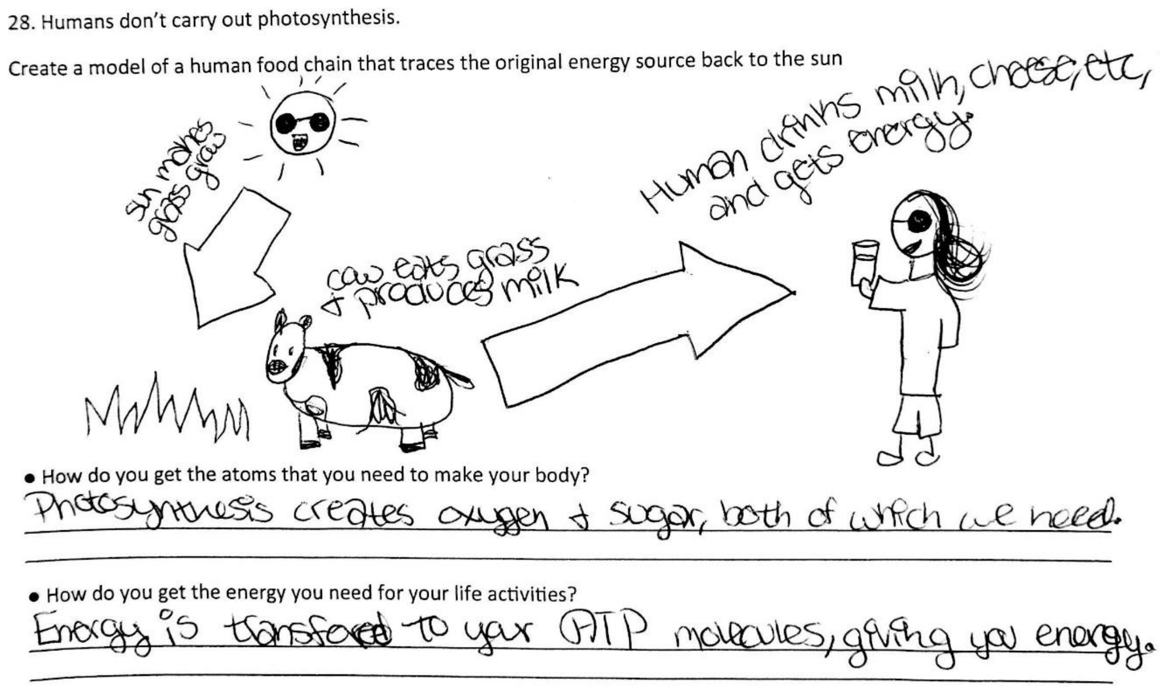

Figure 8. POGIL Question 28: Model creation of a human food chain and energy flow in an ecosystem.

I initially believed that this example of student work presented evidence of three-dimensional learning, but upon further reflection, I recant that assertion. First, the science practice of developing and using models is employed in the answer. The student accurately draws a model of a simple food chain with the sun as the primary energy source and then draws grass, which is a primary producer. The cow, the primary consumer, eats the grass, and the human consumes milk or dairy products from the cow as a secondary consumer. Secondly, the student correctly utilizes the second pillar of three-dimensional learning, crosscutting concepts (CCC). According to Appendix G of the NGSS (2013), the CCC energy and matter allows for "tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations" (NGSS Lead States, 2013, para. 5). The CCC, energy and matter, is used by the student when they describe the outputs of photosynthesis and then can describe how the energy from the food that they eat is transferred into ATP molecules providing them with energy. Finally, the disciplinary core idea (DCI) LS2.B: Cycles of matter and energy transfer in ecosystems, is clearly the conceptual focus of the POGIL questions.

I initially believed that the integration of all three-dimensional elements working together in the question, and the students' answers , were evidence of three-dimensional learning, but that initial assessment was incorrect. In this example, students are asked to draw a model of a human food chain tracing the energy source back to the sun. However, students are not creating an initial model or revising an existing model. They have previously been taught about food chains and energy flow in the unit, so they are simply responding to a question with knowledge that they have already learned.

Constructing Explanations and Designing Solutions

In the next example of student work, students respond to a question asking them to construct an explanation by hypothesizing as is evident in Figure 9.

11. As a group, make a quick list of the foods that you ate during your last meal. Hypothesize what would happen to the supply of those foods if the sun's energy was no longer available.

Ham & egg sandwiches and banana.

If there is no sunlight anymore, the chickens will die because their foods rely on the sun to grow. And there are no longer eggs available if there are no chickens. Bread and banana are from plants, and they will gone, too. No longer plants can cause the death of pigs, too.

Figure 9. POGIL Question 9. This question allows students to construct explanations and designing solutions to a problem. Copyright, The POGIL Project, 2012. All rights reserved. Reprinted with permission.

In this question, the science practice of constructing explanations and designing solutions was used, which allowed the student to construct a theory that provides an explanatory account of the world (NGSS Lead States, 2013). The student proficiently argued what the effects of removing the planet's main energy source would have on both producers and consumers in an ecosystem. The crosscutting concept of energy and matter is used in this question as the focus is on tracking energy into and out of systems. The disciplinary core idea LS2.B: Cycles of matter and energy transfer in ecosystems was the biological concept used in this problem, and all three of these pillars of the NGSS used simultaneously in the response shows that the three-dimension are present, yet they are not constructing explanations and designing solutions because of a continuing process. This provides an example of students responding to questions about concepts they have previously learned, and the question does not reflect the *process* of constructing explanations and designing solutions in a longitudinal learning process.

The next two POGIL questions, shown in Figures 10 and 11, also incorporate the science practice of constructing explanations and designing solutions. The students are given a scenario and are asked to analyze it to come up with a solution.

10. The water cycle is a **closed system**, meaning no water enters from beyond the system nor leaves the system. What does that say about the importance of keeping the water on Earth free from pollution?

If the water on Earth is polluted anywhere in the cycle, it affects the water system in general. Percolation and plants we are limited in what they can do to clean the water. If our atmosphere is polluted, it will then pollute the water. If there is pollution on the ground, runoff will take it to the lakes, rivers, and oceans. The water that is on Earth today is the same water that has been there from the beginning and will continue to be the water that is available to us.

Figure 10. POGIL question 10. In this question, students are asked to construct explanations and design solutions to a problem. Copyright, The POGIL Project, 2012. All rights reserved. Reprinted with permission.

The student answering question 10 has a reasonable understanding of the water cycle, except that precipitation and evaporation were not included in their answer. However, the student did construct a well thought out explanation of the effects of pollution on the water cycle. The crosscutting concept used in this question is: Systems and system models, and according to the Project NEURON crosscutting concepts poster, “a system is an organized group of related objects or components, models can be used for understanding and predict the behavior of systems” ("Novel education for understanding research on neuroscience," 2016, para. 4). The disciplinary core idea that the biological content covers is LS2.B: Cycles of matter and energy transfer in ecosystems, as the question has the water cycle as the core idea.

27. If the number of nitrifying bacteria decreased, what effect would this have on the nitrogen cycle and what type of compounds would accumulate as a result?

the nitrogen cycle would be unbalanced. The nitrites would not be converted to nitrates and the ammonia compounds would accumulate.

Figure 11. POGIL Question 27. This question is another example of students constructing explanations and designing solutions to a problem. Copyright, The POGIL Project, 2012. All rights reserved. Reprinted with permission.

POGIL question number 27, as seen in Figure 11, required the student to construct an explanation for the effects on the nitrogen cycle if nitrifying bacteria were decreased. The student's knowledge of the progression of nitrification in an ecosystem allows them to conclude that the number of ammonia compounds would increase. The crosscutting concept in this question is energy and matter, as the nitrogen cycle represents an energy flow in an ecosystem. The disciplinary core idea in this question is LS2.B: Cycles of matter and energy transfer in ecosystems.

In all the examples of student work in this section, I find it interesting how the manner in which the questions were written allows for the inclusion of a science practice. In many of the questions, the disciplinary core idea stays consistent, as the instructional focus is a biological topic, and disciplinary core ideas represent the science content of what students should learn. Likewise, the crosscutting concepts stay somewhat consistent as well. It is the science practices that have the greatest variance between the questions. As was seen in the previous POGIL questions, the process inherent in real-life science investigations is absent, and students are responding to questions that they already know the answer to, instead of allowing students to construct explanations. After the analysis of student work in the preceding POGIL questions, an example of three-dimensional learning is yet to be identified.

Using mathematics and computational thinking. The next two questions are examples of how students can use the science practice of using mathematics and computational thinking to solve biological problems, and are shown in Figures 12 and 13.

Read This!

Biologists often refer to organic matter by the potential energy that is released when the substance undergoes a chemical change to make carbon dioxide and water. This could occur by burning the organic matter or by an organism using the organic matter in cellular respiration.

14. According to Model 1, herbivore A eats 4 g of grass per day. Using Model 2, how much potential energy does this represent?

.8 kilocalories

15. According to Model 2, how much energy does herbivore A require for cellular respiration each day?

.192 kilocalories

16. Energy lost as either heat to the environment or egested as waste is not considered to be an efficient use by the organism. What percentage of the potential energy of the grass is not efficiently used by herbivore A?

(.208+.35)/.8=.6975 → 69.75%

17. What percentage of the potential energy of the grass is not efficiently used by herbivore B?

(1.6+1.25)/5=.57 → 57%

18. Do the herbivores have the same efficiency in using the grass toward useful purposes? Explain in two or more complete sentences.

No, they don't; herbivore B is more efficient. A uses 69.75% not usefully while B only uses 57% not usefully.

Energy Transfer in Living Organisms 3

Figure 12. POGIL Questions 14 through 18. In this series of questions students use mathematics and computational thinking.

In the first problem, the student uses several models to make energy calculations which were then used to answer questions 14-18. In question 18, the student made a comparison of energy efficiency in the different herbivores.

19. Herbivores A and B are eaten by carnivores.

a. Which category of energy related to the organisms in Model 2 is directly available to the carnivore who eats the herbivores: grass, respiration, biomass or waste?

It will be biomass.

b. What percentage of the original "grass energy" is available to the carnivore if it eats herbivore A?

$\frac{0.05}{0.8} = \frac{5}{80} = 0.0625$, $6.25\ \%$

c. What percentage of the original "grass energy" is available to the carnivore if it eats herbivore B?

$\frac{0.75}{5} = \frac{75}{500} = 0.15$, $15\ \%$

20. Which herbivore is the more efficient food choice for the carnivore? Why?

Herbivore B.

Because it ingests more grasses than herbivore A, so the size may be bigger than A. It also has more biomass value than herbivore A. So Herbivore B is the more efficient for the carnivore.

Figure 13. POGIL questions 19 and 20. This series of questions ask students to use mathematics and computational thinking.

In the second example, as is seen in Figure 13, a similar process is used to calculate how much grass energy is available to a carnivore, and the student uses this information to determine the most efficient food source for the carnivore. Once again, the crosscutting concept of energy and matter is evident in both problems, and the disciplinary core idea LS2.B: Cycles of matter and energy transfer in ecosystems, is the biological content being addressed. The student effectively constructs an explanation as to why herbivore B is more efficient for the carnivore to consume. Both questions use the same crosscutting concepts and disciplinary core ideas of energy and matter, and LS2.B: Cycles of matter and energy transfer in ecosystems. This shows the integration of all three dimensions of the NGSS in both questions, but once again, students are responding to a question presented by the teacher, and they are not using mathematics in the process of solving a scientific problem because of “doing” science. Scientists solve real-world problems by conducting research exploring natural phenomena, and not by answering questions designed to assess their knowledge.

Self-Study Critical Friends Reflections and Validations

In phase I of this study, I asked the research question:

> What issues become evident when developing or selecting instructional units that more closely align to the three dimensions of the NGSS?

Adoption of the NGSS is a contentious and much-discussed topic amongst the science teachers at the high school where I teach. I discovered that many tensions exist when adopting a science education reform that has the potential to be a paradigm shift in how science is taught in a secondary science classroom. The pedagogical changes outlined in the NGSS have the potential to give students the opportunity to think, and problem-solve like scientists and engineers, and these are skills that will help prepare them for college and careers. Students also will have more of a voice in the classroom in a student-centered environment through increased interactions while working in teams with their peers. In an NGSS learning environment, teachers will become more like project managers, providing the resources that students will need to complete their investigations.

Data Analysis

A qualitative analysis was conducted of conversations concerning implementing the NGSS that occurred during twelve Professional Learning Community (PLC) meetings between myself and my critical friends during phase I of the study. For the last several decades, PLC’s have become a means to improve and support teacher skills and knowledge to increase teacher efficacy with the goal of meeting the needs of students (Dogan, Pringle, & Mesa, 2016). PLC’s allow teachers to meet collaboratively, to solve problems, and design solutions related to student learning. Our high school has scheduled four general PLC meetings each week for the school's freshman biology teachers. These meetings have allowed the biology PLC teachers to develop close working relationships where complex issues related to practice can be discussed and solved in an open and frank manner. I was fortunate to have two members of the biology PLC, Angela, and Joan, who both agreed to become my critical friends in this study. The fourth freshman biology teacher in our science department was on maternity leave during phase I of the study and was unable to participate as a critical friend.

A priori codes were brainstormed before initial coding. A priori, or pre-set codes, can come from a range of sources in a study such as research questions, previous research that has been conducted, questions the researcher has concerning the topic of discussion, or the researcher's gut feeling about the data (Taylor & Gibbs, 2010). The digital recordings of conversations that occurred during twelve PLC meetings were transcribed, and I searched through the data for words, phrases, and patterns related to my a priori codes. These initial, level one codes, are labels that I connected to short sequences or phrases in the text that I analyzed. Table 8 lists the pre-set, a priori codes used in phase I.

Table 8

Initial Level 1 A Priori Codes and their Descriptions

A Priori Coding Category	Description
Curricular Issues	What curricular issues and tensions arise in our conversations about the NGSS?
Three-Dimensional Learning	What issues become evident in our discussions concerning 3D learning?
NGSS Implementation Issues	Are tensions about the implementation of the NGSS apparent?
Shifts in Learning	What shifts in learning are we concerned about in implementing the NGSS?

Table 8 Continued

A Priori Coding Category	Description
Phenomena/Models/Storylines	What tensions emerge in our discussions concerning the integration of phenomena, models, or storylines into the curriculum?

Instances of the initial, level 1 codes were identified and selected in the transcripts using the comment feature in Microsoft Word. Highlighted colors were used to categorize the codes and were listed by critical friend name during level two coding in table form (Appendix L). Next, the level two codes were classified and divided into the themes and sub-themes during level three coding, and are shown in Table 9.

Table 9

Primary and Sub-Themes Recorded from Phase I Transcriptions

Primary categories (themes)	Sub-themes related to primary themes
Curricular Issues	• Teachers are not curriculum developers • Teachers as curriculum designers: concerns • State should provide NGSS curriculum • Adoption concerns: what's out there? • Teacher versus state role in curriculum development Curriculum implementation • Modify current labs to make more investigative • Students design labs and direct learning
Curricular Issues	Curriculum acquisition. • Skeptical teachers will be provided NGSS curriculum • Intentions of NGSS designers Curriculum uncertainty • NGSS limits what is traditionally learned • Topic sequence for better understanding • NGSS curriculum takes longer to teach correctly • NGSS trained teachers protect curriculum • Will new curriculum meet NGSS needs? • Achieving NGSS standards not possible

Table 9 Continued

Primary categories (themes)	Sub-themes related to primary themes
Shifts in Learning	Traditional Versus NGSS Learning • Memorization versus understanding • Learning science versus rote knowledge • Science practices versus rote memorization • Figuring out problems versus confirming knowledge • Rote memorization versus understanding • Students can solve problems but don't know facts NGSS Learning • NGSS student-centered learning • Student mistakes during NGSS learning okay • Students should understand performance expectations • Problem-solving most important part of NGSS learning • NGSS limits what is traditionally learned • Higher Education wants students to think like scientists Traditional Learning • Traditional teaching verifies facts • Some students learn to become critical thinkers on their own • Most students learn science traditionally • Some students successful begin taught traditionally • Facts are available at students' fingertips • Lack of unit phenomenon in traditional teaching
Storyline, Phenomena, Models	Unit Storyline Importance • Storyline for the whole year • Unit storyline • Storyline is more involved • 3D learning must have a common storyline Phenomenon-Based Learning • Phenomenon-based curriculum • NGSS Phenomenon based instruction
Three-Dimensional Learning	Understanding 3D Learning • What is 3D learning? • 3D learning takes more time • 3D learning must have a common storyline • Integrate 3D learning slowly • Begin with one of each 3 dimensions at first • Benefits of 3D learning • Benefits of both traditional and 3D learning together • 3D learning provided the "aha" moments • How do you know when 3D learning is happening? • 3D teaching versus 3D learning

Table 9 Continued

Primary categories (themes)	Sub-themes related to primary themes
Teacher Training & Professional Development	How are Teachers Trained? • Teachers must change current practice • Teacher understanding of the NGSS • Teacher adjusts role in NGSS • Most teachers not trained in NGSS • NGSS understanding relies on professional development • Importance of NGSS professional development • Lack of teacher investment in NGSS design

Theme: NGSS Curricular Tensions

One of the themes that emerged from the coded sections of transcripts reveals that teacher tensions exist that are related to aspects of curriculum development and instruction under the NGSS. Understanding these tensions helps provide a lens by which issues that become evident when developing or selecting instructional units that align to the three dimensions of the NGSS are considered. After all, "the goal of qualitative measurement is to look for patterns and get a general feel for how things are" (Boyd, 2016 para. 12). Analysis of the PLC group meeting conversations resulted in categories related to tensions over adopting the NGSS curriculum, including curriculum acquisition, curriculum uncertainty, and curriculum implementation.

Curricular acquisition. The biology PLC discussed issues of how school curricula that are aligned to the NGSS would be acquired. It was considered that in other instances of past educational reforms, teachers would have the burden of developing the NGSS curriculum placed on them. It was argued that teachers are not trained as curriculum developers and that it was the state and local school district's responsibility to provide a well-developed curriculum to practitioners. In one conversation, the biology PLC was discussing whether the state should provide a well-developed NGSS curriculum. Joan, who received some training on the NGSS during the past summer, agreed that the state should provide the school curricula, but she expressed her concerns whether any curricula was available that aligned to the NGSS. Joan said (personal communication, November 2016):

> But what's out there? And what's out there that's going to fit with what we end up with? And depending on where we land, depending on our adoption, is there going to be a curriculum with all the life science PE's and all the earth science PE's that freshman teachers are supposed to cover? That's what makes me nervous. Yes, I would love some sort of binder of phenomena or model-based learning given to me, but I'm skeptical that it exists.

Curriculum implementation. In one discussion, the biology PLC contemplated how we would implement the NGSS without a well-designed curriculum. One teacher argued that we could modify labs that we currently teach and adapt them to the NGSS and make them more investigative. Another suggestion was made by Joan (personal communication, December 2016) that "if we really want to push ourselves towards these standards, we have a lab with the same objectives, hopefully, the same outcomes, and we can present them with a list of materials, but they would design the lab themselves." With the direction of teachers who provide support and resources, students could develop their labs, and then direct their learning after being given a problem to solve. With training and experience in how to integrate all three dimensions into conducting experiments, students can learn how to design solutions to problems. This training would enable students to experience three-dimensional learning. What I noticed during these conversations was the teachers' willingness to make the NGSS work, with a "no matter what it takes" attitude, and that the intentions of the NGSS designers are met.

Curriculum uncertainty. The biology PLC discussed concerns about the lack of NGSS curricula that is currently available, and that if curriculais chosen for adoption, will it be a truly integrated NGSS curricula, or will we be required to make it conform to the NGSS? There was some skepticism that we would be provided a well-designed curriculum, and if we were, would the topical arrangement of the curriculum allow for better understanding of the biology content? One of the PLC members adamantly proclaimed that she would "protect the curriculum," as she had recently received training during a summer in-service, and she would make sure that a poorly designed NGSS curriculum would not be adopted. Other concerns were expressed that the NGSS takes longer to teach correctly making achieving of the NGSS standards impossible to accomplish. Another curricular tension discussed was whether the NGSS limits what is traditionally learned in a secondary biology class. One teacher thought that students would not be ready for college biology content because they would be spending too much time learning to problem solve. These assumptions rest on the idea that there is a set "knowledge" in biology that students must learn to prepare them for college, and there is only a certain amount of time during the school year to "fit" in the content. It will take some readjustment of these assumptions for teachers to shift into the NGSS mindset where core ideas have been added, removed, or deemphasized in the curriculum.

Theme: Shifts in Learning

Another theme that emerged from the biology PLC's discussions about the implementation of the NGSS focused on changes in students' learning under the NGSS. Three sub-themes were identified; how students learn science under the NGSS, how students learn science traditionally, and traditional versus NGSS science learning. In the NSTA position paper on the NGSS, student instruction in the NGSS is required "to engage students in the core ideas through the integration of science and engineering practices while making connections to the crosscutting concepts" (2013, para. 17).

NGSS science learning. Some of the tensions that emerged during our biology PLC discussions concerning how students learn revealed that while NGSS allows for student-centered learning, one teacher felt that the NGSS limits what is traditionally taught in secondary biology courses. Gone from the sequence are traditional units such as plants and animals, and cell biology is integrated throughout the course. In one conversation, learning under the NGSS was compared to working at a job, where the worker is asked to solve real-world problems. We also discussed that it is common for people to learn from mistakes made at work when learning a trade, similarly, it is expected that students will make mistakes while learning how to learn three-dimensionally.

For example, in one conversation, the PLC members discussed how to monitor and support student investigations during NGSS lessons. During this conversation, Angela (personal communication, November 2016) stated that "you pick what lens you're going to focus on and you've got to be okay with the fact that there are going to be areas where they need to improve. You need to leave time for them to make mistakes and learn from them." Angela believes that each group of students is unique. Moreover, differentiation must happen when students are allowed the freedom to explore phenomena. It was also mentioned that problem solving was believed to be the most important aspect of three-dimensional learning, because we agreed that college professors want students to arrive in their classes thinking like scientists. Therefore, students should have an in-depth understanding of the life science performance expectations when they enter college. One of the aims of the NGSS is to provide students with a learning environment where they can learn to solve problems like scientists and engineers.

Learning science traditionally. As a PLC, we agreed that many science students in the United States learn science traditionally and that traditional pedagogy focus on verifying facts disseminated by the teacher. We also discussed how from our experience, that many students we have taught using traditional methods over our careers have become successful, in fact, it was argued that some students learn to become critical thinkers on their own when they leave high school and move on to college or the workforce. Angela, in one PLC discussion (personal communication, November 2016), stated her concern that:

> There are parts (performance expectations) that we're just not going to be able to hit because they were developed by somebody in an office. They don't remember picture day, and fire drill day, and snow days. They say you've got 180 days and so many minutes and you should be able to cover this much stuff. I think that we're making a mistake if we think that any one of these ways, phenomena based or model based, or removing traditional lecture based with worksheets: some kids learn really well that way! I have kids that learned that way when I taught them, and now they're heart surgeons.

Angela, who advocates for differentiated instruction, understands that many students learn science in different ways and that a combination of teaching methods may be necessary to reach "all" students.

Some tension was felt during our discussion over the idea that students are required to memorize a lot of facts, especially in biology which is a very fact laden topic, and we wondered if this is necessary in the modern world where facts are available instantaneously through technology. The source of this tension lies in the belief that many science teachers hold that there is a set group of science knowledge that students must possess when they leave their class. Lastly, we agreed that there is a lack of phenomena based instruction in a traditional unit, in fact, none of the biology PLC members admitted to consistently using phenomena based learning in their practice.

Traditional science learning versus NGSS learning. A final sub-theme related to shifts in learning under the NGSS emerged as we compared learning science traditionally versus learning science via NGSS best practices. A series of dichotomies emerged from our conversations. First was the memorization of facts in traditional science, versus the understanding of science practices in the NGSS. One PLC member argued that having rote knowledge about biology was important in having the vocabulary to solve problems later and having a wealth of science facts did not equate to learning and understanding science through solving problems. Angela (personal communication, December 2016) expressed some concerns about this issue when she said:

> I wonder what happens to our kids when they are taught how something works, especially for our accelerated kids, but when they start chemistry 101 or biology 141 in college, and they're expected to have known these facts, they don't have that knowledge walking into it. They have the ability to figure it out, but they can solve a problem. That's really great, that's part of it, but there is some knowledge that they're expected to have. And right now with the NGSS, these are the things that we're going to expect them to know.

It was agreed by the PLC members that understanding biology could be better achieved through problem-solving rather than by the rote memorization of facts, but knowing biological facts was essential to solving biological problems. This presents a chicken or egg dilemma for teachers. I contend that biological facts can be learned during the problem-solving process.

Theme: Storyline, Phenomena and Models

During several sessions, the biology PLC discussions focused on the importance of having a unit storyline which allows students to learn the science practices of asking questions and constructing explanations. Several sub-themes emerged during analysis of the transcripts; the importance of a unit storyline, phenomenon based learning, and model-based learning versus phenomena based learning.

The unit storyline. “A storyline is a coherent sequence of lessons, in which each step is driven by students' questions that arise from their interactions with phenomena” ("What are storylines?," 2016 para. 2). During our PLC discussions, the issue of a storyline being integrated throughout a unit was discussed on several occasions. We came to consensus as a group that for a unit to be actually aligned with the NGSS, it must have a unit storyline. Evidence of this requirement for three-dimensional learning is found in the EQuIP rubric, wherein Category I: NGSS 3D design, lesson and unit criteria section A, the absence of a unit or lesson explaining phenomena that drive student learning is an indicator of the lesson or units’ failure to align to the NGSS ("EQuIP rubric for lessons & units: Science," 2016, p. 6). We also discussed how a storyline is more involved than having students investigate a phenomenon or develop a model during a lesson. We felt that a unit storyline could encompass both model and phenomena development within the same unit. In fact, we considered the possibility of a biology course with a storyline that extends throughout the entire curriculum, and we brainstormed some ideas for storylines in our curriculum. Lastly, we agreed that three-dimensional learning must contain a storyline, as “a storyline provides a coherent path toward building disciplinary core idea and crosscutting concepts, piece by piece, anchored in students' own questions” ("What are storylines?," 2016 para. 2).

A phenomena based curriculum. The biology PLC understood the importance of a phenomena based curriculum that meets the demands of the NGSS, and we agreed there is an absence of phenomenon based teaching in our current traditionally taught instructional units. However, we struggled to identify phenomena in the life sciences that we could integrate into our curriculum. We discussed strategies to make the ecology II-unit phenomenon based, and we came up with the idea of using owls and their ecological interactions as the storyline for the unit. We questioned whether some of the current labs that we teach could be included in the storyline with the right modifications, and we discussed ways to refocus the lab on problem-solving, rather than the confirmation of knowledge. Overall, we were all on board with attempting to identify phenomena in our curriculum, and how we could use parts of units where we identify phenomenon and try to unify the phenomena into a storyline.

Models versus phenomena. Dichotomous examples were discovered during the biology PLC's discussions on including phenomena and models in our curriculum. One conversation centered on whether the models or phenomena were more suited to biological sciences, and it was suggested that perhaps the science phenomenon helps explain the model. In other words, the unit phenomenon becomes the model of the system that emerges during the units' storyline. A model in the NGSS is "a simplified representation of a system that can explain and help make predictions regarding a phenomena" (Windom, 2016, para. 2). Educators should understand that modeling is a process, where students develop a model so that they can evaluate how effective it is in explaining the phenomenon, then use the model to develop questions and explain relationships, then revise their models if needed (2016). In one discussion, we argued that modeling was found more often in the physical sciences such as chemistry and physics, but that models and phenomena were both requisites for understanding biological concepts. Angela (personal communication, November 2016) expressed the idea that both models and phenomena should be used when she stated:

> So, I think that you do need some of those models to teach the phenomena well. So, I think if we're going to do it well, then we're going to have to have a combination of both. One of the things that are true when using a phenomenon based curriculum is, doesn't that phenomenon become the model for how something works?

I agree with researchers who argue that "models should always be used to help explain and show the relationship with a real-world phenomenon, not simply define a concept" (Windom, 2016, para. 4). One teacher brought up the idea that phenomena and model-based learning were not the only way to teach. She suggested that a combination of these techniques and traditional methods may be a more suitable way to transition into three-dimensional learning.

Three-dimensional learning. Conversations surrounding three-dimensional (3D) learning were varied during our biology PLC time in phase I. We asked questions such as: How do you know when 3D learning is happening? In one of our PLC discussions, Angela (personal communication, December 2016) expressed her concerns about what three-dimensional learning looked like when she said:

> To me it's an idea that somebody that has a Ph.D. in education says is the way to teach, but how do you know, how do you assess in students that something at that degree is actually occurring? What does that look like? Because I feel like I don't know what it really looks like when you can tell that your teaching is producing that kind of learning?

As a PLC, we agreed that for 3D learning to occur, there must be a storyline that allows the learner to tie the crosscutting concepts, the disciplinary core ideas, and the science practices together. We found that it was difficult to find concrete examples of 3D learning. One teacher had recently attended a workshop where it was suggested that teachers should integrate 3D learning into their practice slowly and that they should start with one of each of the three dimensions in a lesson at first. The biology PLC agreed that while 3D learning takes more time to teach, it has the benefit of providing “aha” moments for students. Joan (personal communication, December 2016) made this argument when she said, “I think that traditional methods of teaching also achieve that, but it doesn’t have as much of an “ah-ha” moment for our regular achieving kids because they didn’t just figure it out on their own.” There were questions about distinguishing between 3D teaching and 3D learning, and the benefits of both traditional and 3D learning together, but we were still undecided about what 3D teaching looks like.

Theme: NGSS Implementation Timeline Tensions

The three NGSS model course maps proposed in Appendix K of the NGSS (2013) have been the source of lots of tension in our school district. Several meetings have been held to discuss how the NGSS should be enacted in the district to meet the “all standards for all students” required by the NGSS. Currently, two years of science are required for high school graduation in the district, but many teachers do not believe that all the physical, life, earth, and space standards can be met within a two-year science graduation requirement. It was felt that a two-year model would result in “surface teaching,” and that the science courses developed under this time constraint would just skim the surface of what students should learn three-dimensionally. These implementation tensions have led to a division in our science department between those teachers who are for a two-year model, and those who advocate for a three-year model. Tensions concerning two versus three years to teach the NGSS performance expectations are apparent when Joan (personal communication, December 2016) stated that:

> One of the arguments for the three-year NGSS model is time, and every NGSS training that I've gone to people are like, how do I have the time to teach three-dimensional learning? Now the district is saying teach under the NGSS, only do it in two years which totally freaks me out. Our argument was that we could skim the surface on these PE's that we teach, but we can focus on these. My preference is to do both. These are kids that could end up in STEM careers.

Three-year model advocates believe that a third-year science requirement allows for better 3D learning, while two-year advocates believe that the school's graduation rate will decrease for at-risk students who are unable to pass physics. One suggestion was made to bolster physical sciences during middle school so that students will be better prepared to pass a one year combined chemistry and physics course during sophomore year, but longitudinal curricular changes are out of our control.

Theme: Teacher Training & Professional Development

One of the greatest roadblocks to successful implementation of the NGSS is training teachers how to teach three-dimensionally. The need for teacher training is expressed by a university science methods instructor when she states that:

> The Next Generation Science Standards require a different approach to teaching, and we need to support all teachers—from those in teacher-training programs to seasoned educators—to be successful at this new approach. To achieve this new vision for K-12 science education, teachers will need access to aligned resources and materials, sufficient time for prep work and collaboration, and quality professional development (Madden, 2016, para. 7).

The biology PLC teachers discussed how the way we currently teach science must change, and this change is somewhat reliant on our understanding of the NGSS through professional development. We found that many of the science teachers that we know have not been trained in the NGSS, although one of our PLC members had received some professional development in the NGSS, and she found the training limited, but useful. Joan (personal communication, November 2016) discussed aspects of the NGSS training she had received during a PLC discussion when she said “only recently have I begun to understand the standards. Maybe I’m confident because I went to a workshop over the summer and I’ve been studying the standards, but I have a good idea of what its’ supposed to look like!” During the same conversation, Angela stated some concerns that she has with translating training into practice when she stated:

> The training that I’ve had is mostly a day here and a day there of professional development, and it’s been very useful. But reading about it and watching it in action are two very different things. And that is one of the things that is hard to wrap my brain around, because here’s what you want me to do, but once you start thinking about what that looks like I became disheartened, because when we start practicing NGSS teaching the way it should look like I think we are at risk of missing some of the information that our kids are going to need to graduate.

Part of the tension that teachers expressed in feeling unprepared to teach three-dimensionally was due to a lack of teacher investment in the NGSS design. A perception exists that the NGSS was created by curriculum developers and by education professors who are out of touch with the day by day workings of a secondary science classroom. Table 10 outlines some of the teacher tensions related to practices and assumptions between traditional teaching and NGSS instruction.

Table 10

Teacher Tensions with Practices and Assumptions between Traditional and NGSS Instruction

Teacher tension	Traditional teaching practices	NGSS teaching practices	Assumptions underlying traditional instruction	Assumptions underlying NGSS instruction
Content	Content is delivered by the teacher	Content is explored through a unit storyline	Content is what teachers believe students need to be successful	Content is what "experts" believe students need to be successful
Measuring outcomes	Formative assessments and summative exams	Performance expectations are what students should know	Learning objectives should determine outcomes	Performance expectations determine outcomes
Instructional method	Lecture with confirming labs	Groups explore phenomena using 3-D learning	Teachers direct all aspects of learning	Teachers assist students working in groups
Curriculum	Teachers modify curriculum to at their discretion	The state and local district dictate rigid curriculum	Teachers have freedom to modify curriculum	NGSS sets the curriculum
Content coverage	Taught in units and lessons	Taught by standards	Fast paced instruction to cover material	More time needed for students to explore phenomena

The teacher tensions presented in Table 10 is a comparison between both traditional and NGSS teaching practices and assumptions that I hold concerning conventional and NGSS instruction. These assumptions highlight the ingrained slant in my views towards traditional practices and instruction and my conceptions of what the NGSS brings to instruction and teaching practices. After the enactment of the Project NEURON unit, it will be revealing to discover if any of these assumptions have changed.

NGSS Aligned Unit Selection Process

The Next Generation Science Standards are beginning to be implemented in many of the lead states, however, as indicated by the developers of the EQuIP rubric, there is a "recognition among educators that while curriculum and instruction will need to shift with the adoption of the NGSS, there is currently a lack of high-quality, NGSS-aligned materials" (NGSS Lead States, 2013, p. 1). In phase II of this study, a unit that was developed prior to the release of the NGSS will be used as a representative unit that has the potential to be a model of the type of science unit required by the NGSS. Project NEURON (Novel Education for Understanding Research on Neuroscience) is a program at the University of Illinois Urbana-Champaign that "develops curriculum materials for middle and high school teachers to use in their science classrooms. Each unit addresses various science education standards, including the Next Generation Science Standards, within the context of neuroscience topics and research performed on the University of Illinois campus" ("Novel education for understanding research on neuroscience," 2016, para. 1). Knowing that the Project NEURON unit used in phase II incorporates many of the student-centered practices encouraged by the NGSS, I chose the what makes me tick…tock unit to replace the traditional DNA unit that is taught at the beginning of the second semester. The "tick…tock" unit incorporates phenomena based learning to introduce genetics using circadian rhythms as the unit storyline. In the next section, the EQuIP rubric was used to analyze the Project NEURON unit prior to unit enactment.

Project NEURON Unit EQuIP Rubric Pre-Analysis

The Educators Evaluating the Quality of Instructional Products (EQuIP) Rubric for Lessons & Units: Science, Version 3.0 (NGSS Lead States, 2013) was used to assess the what makes me tick…tock unit for alignment with the NGSS (Appendix F). The intention of the pre-analysis of the Project NEURON unit, which is enacted in phase II of the self-study, is to make a preliminary evaluation of the unit's alignment to the NGSS. During enactment of the unit in phase II, the daily field notes which are recorded using the modified EQuIP rubric will provide additional insights into the units' alignment with the NGSS. During phase III of the study, the data collected during both the pre-analysis and during the unit enactment will be used to make suggestions for aligning the Project NEURON unit with the NGSS.

In category I: NGSS design, section A, which questions if the unit has an explaining phenomenon or if it allows students to design solutions, I found that in this unit student learning is driven by investigating the question: What makes me tick…tock? Circadian rhythms are the phenomenon that drives the storyline in this unit. Students examine various aspects of circadian rhythms during each of the eight lessons, and ultimately answer the driving question in lesson 8: When should the school day begin? A detailed explanation of phenomena based learning should be included at the beginning of the unit to inform teachers using the unit how it supports three-dimensional learning to improve the unit. I gave the unit an "extensive" evidence of quality rating as to its inclusion of an explaining phenomenon. This unit's strength is in its consistent phenomenon based storyline.

In section B of category I: NGSS 3D design, each of the three dimensions and their inclusion in the unit is assessed. I found that many of the units' lessons incorporate science practices. For example, in lesson one, the science practice: planning and carrying out an investigation is used. Lesson two utilizes the science and engineering practice (SEP) developing and using models, and lesson four uses the SEP: analyzing and interpreting data. I found that because the unit was written prior to the completion of the NGSS, it uses both the NSES content standards, and the AAAS benchmarks (American Association for the Advancement of Science, 1993; National Research Council, 1996), instead of the NGSS life science disciplinary core ideas (DCI's). The NGSS crosscutting concepts (CCC's) are not identified in the lesson, although through a close analysis of each of the unit's lessons, some CCC's may be determined. I suggest that the unit could be improved by the addition of a unit master list of SEP's used in each part of the unit, and list where they are incorporated in the unit introduction. This would allow teachers using the unit see the "big picture" of how the three-dimensions of the NGSS are utilized throughout the unit. I also suggest that the lessons in the unit should be aligned to the NGSS life science DCI's and PEs. If they were included with the SEP's and CCC's at the beginning of the unit, and within each lesson, a clearer picture of three-dimensional learning in the unit would emerge. Finally, I suggest that an analysis should be made to identify the CCC's in each lesson. I gave the unit an inadequate evidence of quality rating for an unclear alignment with the three-dimensions of the NGSS

In category I: NGSS design, section C, the units' overall integration of the three dimensions was assessed. I believe that integration of the three dimensions may be evident upon close evaluation and conversion of the unit from the earlier NSES and AAAS standards to the NGSS, but this process would be incredibly time-consuming. I found that some science practices are evident in the unit, and the unit is a well-designed phenomenon based learning unit. However, I suggest that alignment of the unit to the NGSS' CCC's and DCI's is lacking, and there is a need to identify the NGSS PE's in the unit. As a result of this evaluation, I gave category I: NGSS 3D alignment an overall rating of one, which indicates that "there is adequate evidence to meet at least one criterion in the category, but insufficient evidence for at least one other criterion" ("EQuIP rubric for lessons & units: Science," 2016, p. 7).

Usually, if a unit scores less than a two in category I, the evaluation stops as the unit is deemed unaligned with the NGSS. However, I decided to continue evaluation of the unit using the EQuIP rubric as the data collected will help with my analysis and suggestions for improving the unit in phase III of the study. Category I: 3D design provides an additional evaluation for units only. In section D, unit coherence, I found that the NGSS performance expectations are not used in the unit, however, with analysis, the NGSS PE's could be identified. Each lesson does build on prior lessons knowledge and understanding of the phenomena, and I suggest that the unit be aligned to the NGSS PE's to improve the inadequate evidence of quality rating.

In category I, section E, multiple science domains, I discovered that DCI's from other domains are not indicated in the unit, and I suggest the integration of DCI’s from other disciplines such as earth and space science be completed. Also, I suggest that identification of the CCC's that could be used to investigate the phenomenon across domains is made. Additionally, I found that there was no evidence of math and ELA integration, and suggest that the unit be modified to include both math and ELA standards. Because of these findings, the rating for category I, NGSS 3D designed units received a one, which indicates that there was adequate evidence for some criteria in category I, but inadequate, or no evidence for at least one criterion in sections A through C.

In category II: NGSS instructional supports of the EQuIP rubric, lessons and units are evaluated as to whether they include “clear and compelling evidence” of relevance and authenticity, student ideas, building progression, scientific accuracy, differentiated instruction, teacher support for unit coherence, and scaffolding differentiation over time. In the first category, section A relevance and authenticity, I found that students experience the phenomenon of circadian rhythms through a variety of methods including; investigations, collecting sleep pattern data, using model organisms, model genes, case studies, data analysis, building models, and readings. Each new lesson is conceptually connected to the previous lesson. I suggest that a chart be included in the unit introduction that diagrams how the phenomenon flows and integrates into each lesson. I gave section “A” an “extensive” rating.

In section B, student ideas, I found that student ideas are expressed through conversations about the phenomenon in their groups, and through teacher interactions with groups in the lessons. Additionally, students fill out surveys and answer questions in classwork and homework assignments. Section B received an “extensive” rating. Part C measures how the unit builds progressions through prior learning in all three dimensions of the NGSS. I found that prior student knowledge is developed progressively throughout the lessons, however, without NGSS DCI and CCC alignment, it is hard to tie this into 3D learning. I suggest that aligning the unit’s CCC's and DCI's to the NGSS will better allow for 3D learning progression identification. Because of these issues, section C earned an “inadequate” rating.

The scientific accuracy and grade appropriate level of the unit is assessed in section D. I found that the accuracy of the scientific information in this unit is impressive and there are advanced biological concepts introduced in the unit that are appropriate to accelerated biological learning. Some of these concepts include epigenetics, DNA structure, protein synthesis and structure, actograms, RNA structure and transcription, and much more. I suggest that the lessons include interactive videos of conceptually challenging biological processes such as DNA replication, transcription, and translation. Section D received an “extensive” rating.

In section E, the inclusion of differentiated instruction guidance for teachers in the unit is assessed. I found that although each lesson contains a section on how the lesson can be adapted, and how accommodations can be made, this is mainly with respect to procedural issues, and not indications for learner scaffolding or differentiation. I stated that the unit could be improved through the addition of suggestions for how to best accommodate students with special needs. Section E received an “inadequate” rating. The category II: instructional supports – lessons received a rating of one, signifying that adequate evidence of quality for at least two criteria in the category was met.

Category II is further divided into two sections: F and G. In section F, teacher support for unit coherence is analyzed. I found that the unit provides extensive teacher support in linking student engagement across lessons using well-written questions in each lesson. Thus, section F received an “extensive” rating. In section G, scaffolded differentiation over time was assessed, and I discovered that scaffolding differentiation is evident throughout the unit. For example, each lesson builds on aspects of the phenomenon that eventually allow students to design a solution to the problem. Thus, the overall rating for category II: NGSS instructional supports was two, indicating that there was “some evidence for all criteria in the category and adequate evidence for at least five criteria, including A” ("EQuIP rubric for lessons & units: Science," 2016, p. 11).

Category III: monitoring NGSS student progress, measures how the lesson or unit allows for the monitoring of student advances in three-dimensional learning while students attempt to make sense of the guiding phenomenon of the unit or lesson. Category III is divided into six sections, the first four sections, monitoring 3D student performance, formative assessments, scoring guidance, and unbiased tasks and items, are scored separately from the last two sections, coherent assessment system, and opportunity to learn. In section A, monitoring 3D student performance, I found that evaluation of this aspect is undetermined until the unit is aligned with three-dimensional learning, and suggested that it be re-evaluated after aligning the unit with the NGSS. Thus, there was no evidence of quality in section A.

Formative assessment use in the unit is evaluated in section B. I found that there were multiple formative assessments included throughout the unit including homework, reading comprehension, monitoring student progress, and worksheets. However, no multiple-choice assessments are listed in the unit. My suggestion is to develop multiple choice questions for each unit. Thus, section B received a rating of “adequate.” Yet, section C, scoring guidance, received a “no evidence of quality” rating as no rubrics or scoring guidelines were available to the teacher in the unit. There was some instance of completed table examples, but not an existing rubric system. I suggest that rubrics and scoring guidelines be developed for all unit assessments.

Section D: unbiased tasks and items, was found to have adequate evidence of quality. The tasks in this unit seem unbiased. However, they are more suited to accelerated biology students. I believe that academic biology students would have a difficult time with some of the tasks, the vocabulary, and concepts in this unit. I suggest that the student target audience should be stated in the unit introduction and suggestions for differentiating the unit be made. Because of this evaluation, criteria, A-D received an assessment score of one, signifying that there was adequate evidence for at least two criteria in the category.

In the final two sections E and F, the units’ coherent assessment system and the opportunity to learn are assessed. I found that no unit pretest or post-tests are included, nor are unit summative assessments included. I suggest that unit pre-test and post-tests be developed. Due to the lack of summative assessments, category E was found to have “no evidence of quality.” In section F, the opportunities for students to learn was evaluated. There were multiple and varied formative assessments in the unit, but it is hard to determine whether the performance of the students would align with the learning opportunities in this unit without the CCC's and DCI's being aligned to the NGSS. I suggest that the unit is brought into line with the NGSS before 3D learning opportunities can be properly assessed. The overall rating for criteria A-G in category III was a zero, meaning that there was adequate evidence for no more than two criteria in the category.

After an analysis of the Project NEURON, what makes me tick…tock unit, the overall rating for the unit was an “R,” which indicates that the unit needs revision, meaning it is partially designed for the NGSS but needs significant revision in one or more categories. Even though the unit did not receive a high-quality NGSS unit rating, I believe that through a close analysis of the units’ disciplinary core ideas, crosscutting concepts, and science practices, a much better rating could be achieved. This close analysis will take place during phase II of this study, and the final suggestion for the units’ revisions will be made in phase III of the study.

Summary of Phase I Findings

In Phase I of this self-study of my practice, I began by recounting the creation of a DNA and cell division unit that was ultimately rejected. Through an analysis of the unit, I discovered that at the time I wrote the unit, I did not possess a clear understanding of three-dimensional learning that would have enabled me to integrate a unit storyline and phenomena successfully. I also realized that as this was my first attempt at curricular design, and because I have not had formal university instruction in curricular design, that I did not have the curricular development understanding required to write a cohesive NGSS centered unit. It was also at this point in my study that I came to the realization that my identity as a traditional teacher was impacting my ability to shift to NGSS aligned pedagogy, and the decision to conduct a self-study to change my practice was undertaken. I finally realized that the outdated “best practices” I had been using for several decades needed to be reconsidered and that this self-study was helping me to accomplish that. Additionally, I realized that changing my practice would be a gradual process was revealing. I assumed that I would be expected to change into an NGSS aligned teacher right away, but through discussions with my critical friends, we agreed that neither teachers nor students could be expected to make a quantum leap into the NGSS. The EQuIP rubric evaluation of the DNA and cell division unit showed non-alignment with the NGSS.

Next, the ecology part II traditional unit was analyzed using the EQuIP rubric, and it was found not to be in alignment with the NGSS, however, I made the discovery that the biology content of the unit was somewhat in alignment with ecology DCI’s, which was disconfirming to my original assumption. I also found that the unit fell short in its use of science practices, a unit storyline, and guiding phenomenon. All data collected during the traditional unit enactment verified these results, and the self-study class portrait of one of the units’ lessons confirmed that the traditional teaching methods that I have been using for several decades are teacher-centered.

The analysis of student work in phase I provided what I thought was the first identifiable instances of three-dimensional learning so far in the study, but I later reconsidered this assertion due to the absence of longitudinal science practice development. I also came to the realization that three-dimensional learning was a process, and the POGIL questions were asking students to use prior knowledge to answer teacher directed questions. However, the POGIL assignment examples of student work did reveal a connection of the science practices of model creation, constructing explanations, and using mathematical and computational thinking to crosscutting concepts and disciplinary core ideas, just not in a longitudinal way. The analysis of what I initially believed was evidence of three-dimensional learning in student work will cause me to change my perspective as I examine student work later in phase II during the Project NEURON unit enactment. I now know to look for evidence of model creation, application, and revision as signs of three-dimensional learning, as well as the longitudinal use of the three-dimensions as students explore phenomena.

Qualitative analysis was used to analyze critical friend discussions, and a priori codes were used to identify specific themes and subthemes in the data. The NGSS curricular tensions relating to curriculum acquisition, curriculum implementation, and curriculum uncertainty were identified and discussed. Another theme was established in the discourse which highlighted critical friends concerns in NGSS shifts in learning from a traditional, teacher-centered model, to a student-centered model of learning. Next, tensions and concerns surrounding the inclusion of unit storylines, and phenomena versus model-based learning were identified and discussed. NGSS timeline implementation tensions, especially surrounding the two-year, versus three-year life science model, revealed teacher angst and issues concerning the importance of teacher training and professional development when transitioning to a new science education reform. The richness of the data collected during the PLC critical friend discussions brought to the surface many curricular and instructional issues inherent to the adoption of the NGSS. The data that was collected and analyzed during the deliberations in phase I of the study has given me a new lens through which to examine the transition to a unit that more closely aligns to the NGSS in phase II of the study.

The self-study phase I concept map gave a visual representation of a traditional teaching episode, and tag clouds allowed for the identification of issues and tensions when field notes were written more apparent through a visual graphic.

The pre-analysis of the Project NEURON unit using the EQuIP unit was somewhat disconcerting. I had assumed that the unit would be much more aligned to the NGSS than it was, however, the technicality of the unit not having been purposefully aligned to the NGSS, as it was written prior to the NGSS's implementation, resulted in the rubrics' recommendation that the unit be revised and brought into line with the NGSS. I found that the unit had the one critical aspect of the NGSS that was missing in the traditional unit analysis: The unit has a well-integrated storyline. This inclusion, along with science practices and crosscutting concepts found in the unit, gave the unit promise to be a model NGSS unit with revisions. Suggestions for these changes and a final determination of possible alignment with the NGSS will be made in phase III of this study after unit enactment in phase II.

Finally, a self-study education-related life history was made so that I could introspectively reflect on episodes in my life that have influenced how I have developed into the teacher and a researcher I am, and why my teaching falls on the traditional side of the spectrum. These reflections may be helpful in eliciting teacher change during this self-study. During phase I of this self-study, I asked the research question:

> What issues become evident when developing or selecting instructional units that more closely align to the three dimensions of the NGSS?

Through a close analysis of my shortcomings during curriculum development, and through self-study research, I can answer this research question. First, the realization that I did not have an adequate or thorough understanding of three-dimensional teaching and learning prior to unit development resulted in the DNA and cell division units' failure to align with the NGSS. Also, through the writing of detailed field notes using the modified EQuIP rubric which was backed up via audio and video recordings, I discovered that many issues and tensions underlie the adoption of the NGSS, both personally, and with my critical friend's input. These issues and tensions are presented in Table 11.

Table 11

Instructional Unit Selection and Development Issues and Tensions Evident During Phase I

Phase I – Instructional Selection and Development Issues and Tensions
I had an inadequate understanding of three-dimensional learning
The biology PLC had concerns about the NGSS timeline implementation
Tensions surrounding acquiring and implementing NGSS curricula were apparent
There was uncertainty about unit storyline, phenomena, and models in instructional materials
Shifts in learning in traditional versus NGSS aligned instruction was contemplated
The need for NGSS teacher professional development was expressed

These tensions and issues were found to be centered around curricular uncertainty, curricular implementation, acquisition, shifts in learning from traditional to NGSS alignment, the inclusion of unit storylines, models and phenomena in curricula, NGSS implementation timeline tensions within our science department, and the need for teacher professional development.

The second research question in phase I asks: How closely do the characteristics of my practice align to three-dimensional learning when teaching biology traditionally? I found through the evaluation and analysis of the ecology II unit, that while some crosscutting concepts and disciplinary core ideas were used in the unit, the lack of a unit storyline and the non-inclusion of a model of phenomenon based learning resulted in the failure of the unit to align with the NGSS. I have noticed through the evaluation of units using the EQuIP rubric that disciplinary core ideas and some crosscutting concepts are used when I teach biology traditionally, but the non-alignment of my practice to the NGSS centers around the absence of a unit story line and phenomenon, as well as science practices.

The NSTA’s position statement on the implementation of the NGSS declares that “the vision of the Framework and the NGSS is to engage students in the core ideas through the integration of science and engineering practices while making connections to the crosscutting concepts" (National Science Teachers Association, 2013, p. 1). This definition of three-dimensional learning highlights the point that the integration of all three dimensions is crucial to the NGSS. In phase two of this study, the search for three-dimensional learning in the quest to change my practice will continue with the enactment and analysis of the Project NEURON what makes me tick…tock unit.

Phase II Project NEURON Unit Enactment

During phase II of this self-study, an analysis of the data collected during the implementation of the Project NEURON unit: *What makes me tick…tock? Circadian rhythms, genetics, and health* ("Novel education for understanding research on neuroscience," 2016) will be made. In the first section, the research questions for phase II are presented, then an analysis of data collected via field notes during the unit enactments will be made. Next, discussions that occurred with my critical friends concerning the implementation of an NGSS curriculum will be qualitatively analyzed. Following this, a self-study student work analysis will be presented to continue my search for evidence of three-dimensional learning. A self-study class portrait of a lesson in the Project NEURON unit will be submitted to illustrate the shift to a student-based learning model in the unit. In the next section, a self-study concept map and tag clouds will be shown to help highlight data collected via field notes using the modified EQuIP rubric during the unit enactment. Finally, the phase II findings will be summarized and discussed.

Phase II Research Questions

In the following sections, data that was collected during the enactment of the Project NEURON unit will be analyzed to answer the phase II research questions. The research questions for phase II are:

1. How does implementing a biology unit that aligns to the NGSS change my instructional methods, and what issues become evident during this implementation?
2. How closely does the Project NEURON unit align to the NGSS and three-dimensional learning?

In phase II of this self-study, a science unit produced by Project NEURON ("Novel education for understanding research on neuroscience," 2016) was enacted for twenty school days in my secondary biology classroom. While the instructional unit was not originally designed for the Next Generation Science Standards (NGSS Lead States, 2013), many of the components suggested by the National Research Council's *Framework* (2012) are present in the unit. These components include; science practices and a unit storyline/phenomenon, and in certain lessons, crosscutting concepts and disciplinary core ideas have been integrated into the unit (Talbot & Hug, 2013). At the time that this self-study was considered for enactment, very few examples of NGSS aligned curricula were available. There were several reasons that the Project NEURON what makes me tick…tock unit was selected. First, the unit was developed at the local university, so any questions about the course sequence, material, and content could be answered. Secondly, I consulted with Barbara Hug, the university's science curriculum development expert when I wrote both a microbiology, and the DNA cell division unit, and she offered her support and advice during the unit enactment. Finally, the unit was written with science practitioners in mind, and its detailed and well-written lesson plans, including numerous activities and formative assessments, provided a substantial curricular base to enact a shift in my pedagogy.

Field Notes – Project NEURON Unit Analysis

In phase II of this study, data was collected for twenty instructional days using the revised EQuIP rubric field notes form created using Google Forms while enacting the Project NEURON, what makes me tick…tock unit. During an initial survey of the curricular unit, an approximate timeline of four weeks of instructional time was calculated using the lesson timeline estimates found in the curriculum. However, after the unit enactment began, I found that each lesson was taking nearly twice the estimated time that was suggested in the curriculum. A decision was made to limit the unit's enactment to approximately four weeks of data collection that was stipulated during IRB approval. Failing to reduce the enactment time would have put the completion of the remaining district required instructional units during the second semester at risk.

Many of the units' lessons were completed in their entirety, but to meet the instructional timeframe allotted to the Project NEURON unit several instructional adaptations were made to the unit. First, lesson one: What is a circadian rhythm, and lesson two: Why do scientists study fruit flies to find what makes us "tick," were both taught in their entirety. In lesson three: How can genetics change your clock; snap beads were used in place of Velcro strips and pipe cleaners to construct models of DNA and investigate the "per" mutations. In lesson four: Tick tock…broken clock, was taught in its entirety, but in lesson five: How do environment and modern society influence our rhythms, students conducted the first lesson activity where they read articles that highlighted interactions between circadian rhythms and the environment, but they did not perform the second part of the lesson where they measured light exposure around the school. Lesson six: What happens to humans when regular rhythms are disrupted, was completed in its entirety. At this point in the unit we ran out of time, so lesson seven: How can epigenetics change your clock, was not covered, and lesson eight: When should the school day begin, where student use the data from their sleep studies to make a claim from evidence as to when the school day should start, was included as a question on the unit summative exam (Appendix M).

As the unit was enacted, I carefully considered the instructional methods that I had used during the ecology II unit, and I used those methods as a baseline by which to compare the instructional methods I employed in the Project NEURON unit. I conducted an analysis of my teaching style, including the underlying assumptions and values that I felt contributed to my self-identity as a traditional teacher. As I began the unit, I felt apprehensive knowing the pedagogical shift that was in store for both myself and my students. While my instructional methods had evolved somewhat during two decades that I had been a science teacher, this unit provided a student-centered approach that was considerably different from the way I typically teach.

One tension that I experienced during my analysis of the Project NEURON unit was the difficulty that I had accurately identifying the three-dimensions of the NGSS while enacting the unit. During the pre-assessment of the unit using the EQuIP rubric in phase I, I found that because the unit was not originally designed to align to the NGSS, that there were issues in its alignment to the three-dimensions. As a result, a great deal of time was spent searching for content related aspects of the unit that aligned to the NGSS. These concerns and uncertainties followed me into the unit enactment analysis as I struggled to identify science practices, crosscutting concepts, and disciplinary core ideas in the instructional unit. I do not claim to be an expert in science unit evaluation, but I believe that the initial experience of carefully analyzing the alignment of instructional units with the NGSS provided me with a foundation to build on in future science unit evaluation experiences.

An analysis of the data collected during the twenty-day instructional period during phase II revealed that there were four types of instruction in the Project NEURON unit, which were the same number and types of instruction that were used during the ecology II unit. Table 12 shows the breakdown of instructional days and the types of instruction used during phase II.

Table 12

Breakdown of Instructional Days During Phase II

Type of Instruction	Number of Days
Direct Instruction	0
Exam/Quiz	1
Review/Makeup	1
Lab/Research/Presentation	18

The Project NEURON unit had eighteen labs, research, and presentation days as compared to the eleven days in the ecology II unit. The day's designated lab, research, and presentation were all student-centered instructional days. The most significant difference in instructional days between the two units was in the number of direct instruction days. The Project NEURON, unit being student-centered, had zero direct instruction days. Instead, I would normally begin the class period by giving a short description of what the students would be accomplishing that day, including some procedural tips at the beginning of the period, and then students would work in cooperative groups for the remainder of the period. There were many formative assessments included in the Project NEURON lessons, but unit summative assessments were not provided. Also, one day was spent in review before students took the summative unit exam that I developed to meet the school districts' requirement that two summative assessments be given per instructional unit.

The lab, research and presentation days varied in teacher instructional moments. The Project NEURON curriculum prescribes many teacher/student questioning episodes to introduce students to new concepts, to assess student prior knowledge or to summarize an activity, but almost all the instructional time was spent in students-centered cooperative groups.

Lessons' anchoring phenomenon/problem. My initial attraction to using the Project NEURON unit as a pedagogical tool which could shift the centeredness of my classroom, besides being a locally developed product, was due to its nature as a phenomenon driven unit of instruction with a storyline. It was pointed out earlier in this chapter that in a phenomenon driven science classroom the learning is led by the students where they are given questions to research and are not fed the answers. This encourages richer engagement with the course content as students must actively navigate the core science ideas, instead of just passively learning about content. I found that the level of lesson and unit level integration of a storyline and phenomenon aligns with what is suggested by the NGSS Fact Sheet (2013) when it suggests that:

> Students engage with phenomena and design solution: In instructional systems aligned to the NGSS, the goal of instruction is for students to be able to explain real-world phenomena and to design solutions using their understanding of the Disciplinary Core Ideas. Students can achieve this goal by engaging in the Science and Engineering Practices and applying the Crosscutting Concepts (2013, para. 10).

Table 13 lists the anchoring phenomenon or problem found in each of the unit's eight lessons.

Table 13

Phase II - Lesson's Anchoring Phenomenon or Problem (Circadian Rhythms)

Tick…Tock Unit Lesson	Lesson's Anchoring Phenomenon/Problem
What is a circadian rhythm?	What makes me tick…tock? What makes me sleep?
Why do scientists study fruit flies to find what makes us "tick"?	How do environmental issues and genetics impact an organism's circadian rhythms?
How can genetics change your clock?	What role does genetics play in an individual's circadian rhythm?
Tick tock… broken clock	What happens when your clock is disrupted?

Table 13 Continued

Tick…Tock Unit Lesson	Lesson's Anchoring Phenomenon/Problem
How do environment and modern society influence our rhythms?	How does the environment, particularly exposure to light, affect circadian rhythms?
What happens to humans when normal rhythms are disrupted	What are the adverse complications of circadian rhythm disruptions on human health?
How can epigenetics change your clock?	How do changes in chromosome structure influence gene expression?
When should the school day begin?	What is your argument for when the school day should start?

Table 13 shows that in the Project NEURON unit has an overarching anchoring phenomenon of circadian rhythms, and each of the eight lessons has a guiding question that students use to help them explore different aspects of the lesson's phenomenon.

Project NEURON unit science practices. One of the strengths of the Project NEURON unit as a potentially NGSS aligned unit was in the integration of science practices. Several of the lessons had specific science practices identified that aligned to the *Framework* (2012). For example, lesson 1 of the "tick…tock" unit identifies the science practices of planning and carrying out an investigation, and analyzing and interpreting data. The incidences of science practices that I identified while enacting the unit are displayed in figure 14.

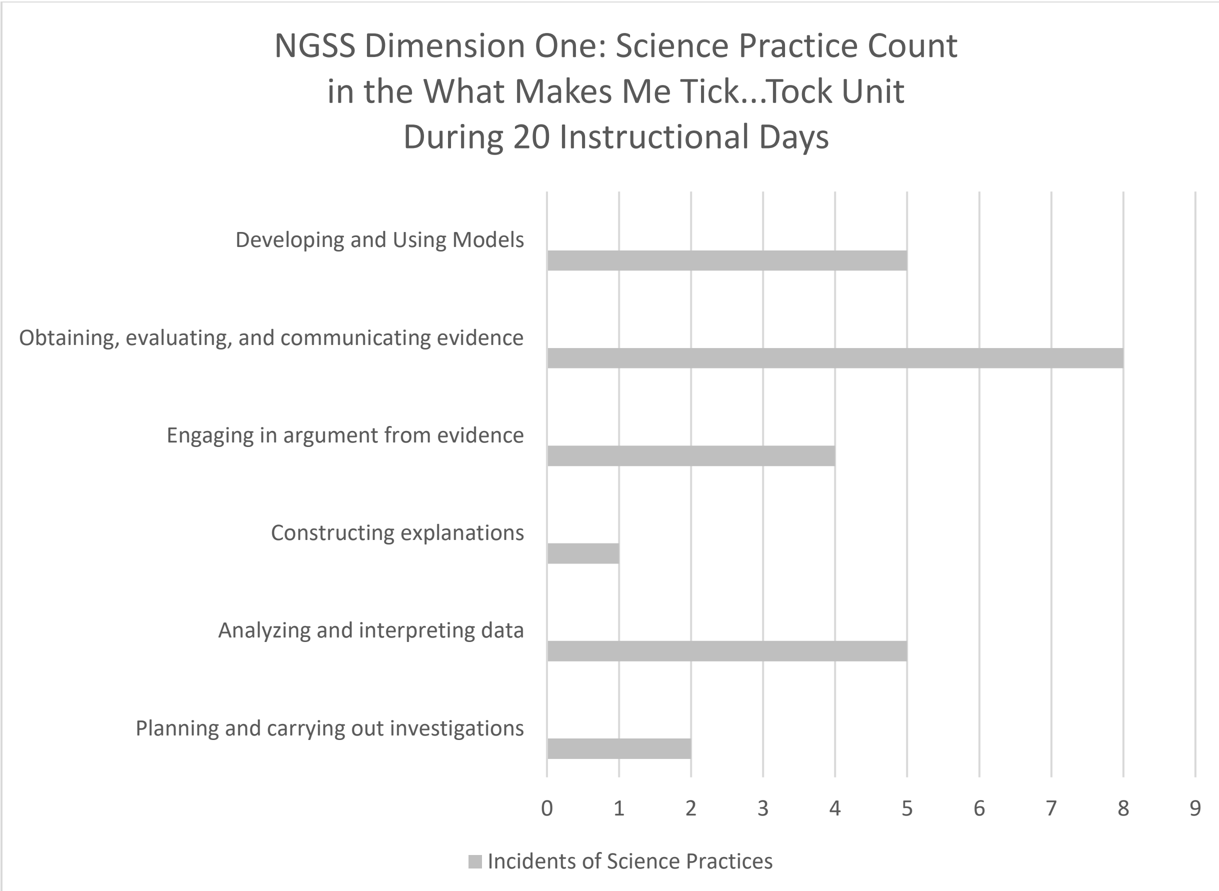

Figure 14. Science practices count in the what makes me tick…tock unit.

I found it difficult to accurately identify some of the science practices within the Project NEURON unit that were not expressly identified. Some of the science practices were expressly stated in the lessons, while others were not. My analysis of the lesson's science practices was a "best attempt" at identification, and I believe that as I become more accustomed to working with the NGSS science practices in the future that the identification process will become more precise. However, I did find that students were actively involved in using the NGSS science practices during each lesson in the unit, which differs significantly from what they would experience in a traditional, teacher-centered setting.

I discovered that many lessons in the unit had various integrated science practices. I identified five incidents of the science practice (SP) of developing and using models in the lessons that were enacted. An example of the use of models and model revisions was evident when students developed their initial models of the sleep/wake cycle**,** and students then revised the models several times throughout the lesson and unit. Many of the unit's lessons contained worksheets and articles that student groups evaluated, and then shared their findings with other team members, or groups. I identified eight incidents of the science practice of obtaining, evaluating, and communicating evidence during the lessons we covered, and four incidents of engaging in argument from evidence. Additionally, I recorded one incident of constructing explanations, five incidents of analyzing and interpreting data, and two incidents of planning and carrying out investigations.

Project NEURON unit crosscutting concepts. In the analysis of the use of crosscutting concepts (CCC's) during the what makes me tick…tock unit, I found that only four of the seven CCC's were present. This was the same number of CCC's identified in the ecology II unit.

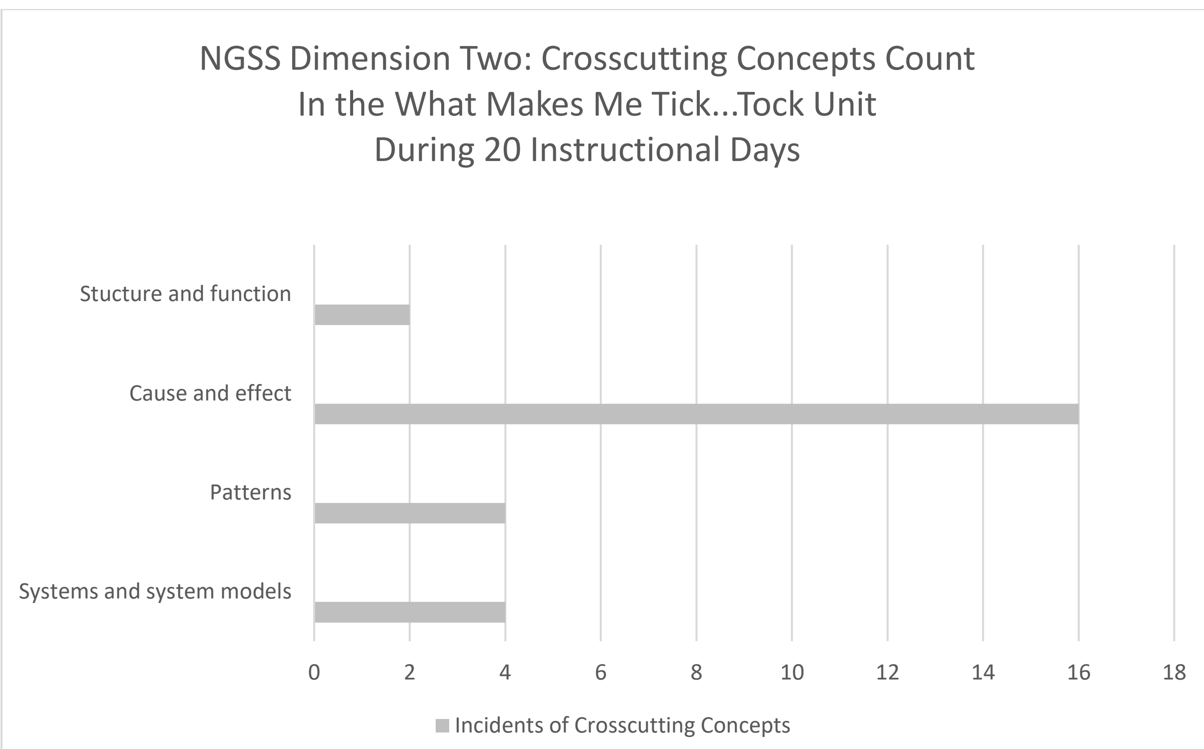

Figure 15. Crosscutting concepts count in the what makes me tick…tock unit.

During students' investigation of circadian rhythms in the instructional unit I found that the crosscutting concept (CCC) cause and effect was used extensively. According to the NGSS crosscutting concepts poster available on the Project NEURON website ("Novel education for understanding research on neuroscience," 2016), cause and effect are described as "events have caused, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated is a major activity of science and engineering" (para. 2). Throughout the unit, students were asked to evaluate the cause and effects of different variables on sleep/wake cycles. For example, students explored the effects of temperature, light, and genetic mutations on circadian rhythms, as well as the environmental and societal factors on sleep patterns. The CCC of structure and function was investigated in relationship to DNA, RNA, protein structure and circadian rhythms, and I found that the CCC of patterns was used throughout the unit, especially when students investigated their sleep patterns in the sleep study.

Project NEURON unit disciplinary core ideas and performance expectations. One of the greatest difficulties that I experienced during the evaluation of the Project NEURON unit was the identification of the disciplinary core ideas (DCI's). The tension that I initially felt was reduced when I came to the realization that the unit would not be able to replace the DNA and cell division unit that was being taught concurrently by my critical friends at the beginning of the second semester. I realized that the unit was developed with an emphasis on neuroscience, and perhaps not as a replacement for freshman introductory biology content, but as a supplement to it. It is due to this fact that I experienced a great deal of difficulty connecting the NGSS life science DCI's to the unit. Figure 16 shows the DCI's that were identified in the Project NEURON unit.

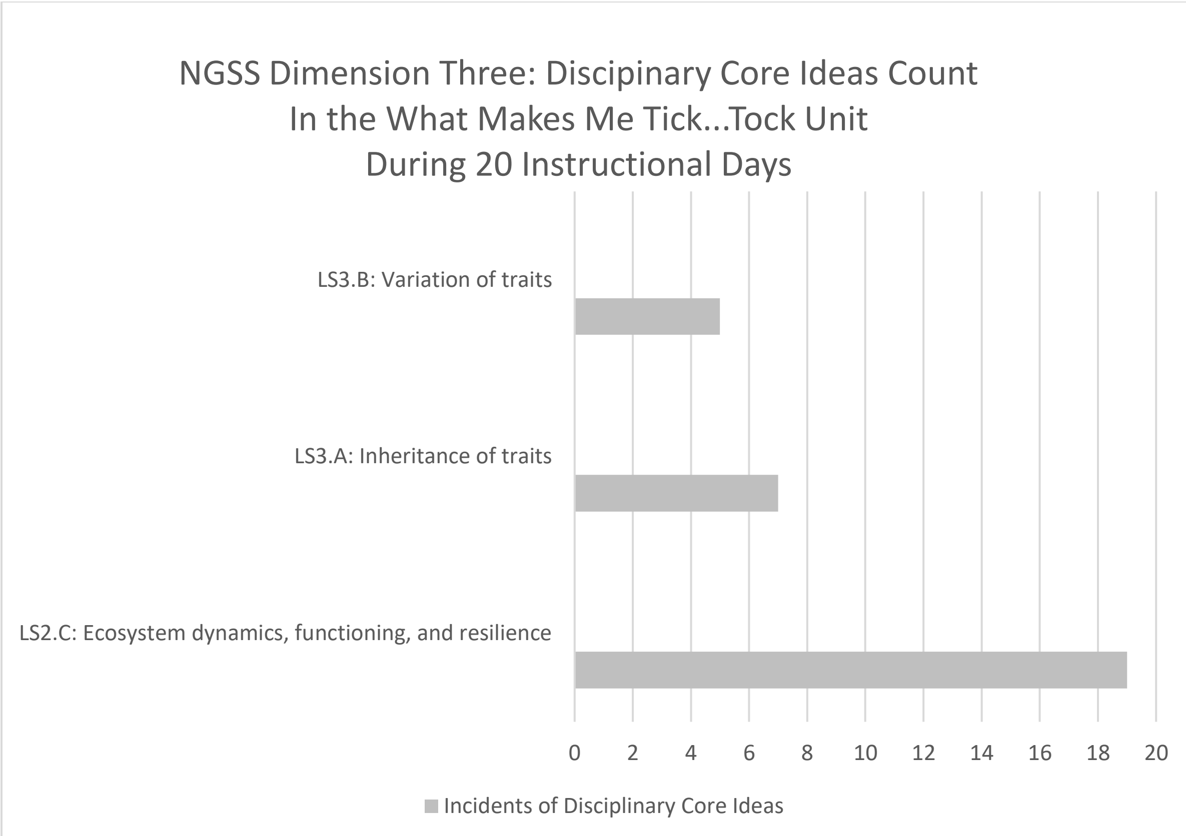

Figure 16. Disciplinary core ideas in the what makes me tick…tock unit.

I determined that the DCI *LS2.C:* Ecosystem dynamics, functioning, and resilience, was the predominant biological content explored in the unit. My reasoning for this identification was that circadian rhythms result from an organism's interactions with abiotic factors in an ecosystem. The NGSS description of LS2.C describes anthropogenic changes, those which are induced by human activity in an environment, and the disruption that can result in an ecosystem (2013). Although I was not able to identify specific content related to circadian rhythms in the NGSS, I believe that ecological content is the best DCI match. Additionally, the inclusion of DNA, mutations, and protein production is clearly related to biological content found in LS3.A, inheritance of traits, and LS3.B, a variation of traits. The disconnect between the phenomenon of circadian rhythms was the primary reason that the what makes me tick…tock unit scored a two on the EQuIP rubric pre-assessment.

As was discussed during analysis of the ecology II unit, I believe that the NGSS performance expectations (PE's) are very narrow in their focus. This presents problems for curricula that is not expressly written for the NGSS. According to the description of life science performance expectations in the NGSS (2013):

> The performance expectations for high school life science blend core ideas with scientific and engineering practices and crosscutting concepts to support students in developing useable knowledge that can be applied across the science disciplines. While the performance expectations in high school life science couple particular practices with specific disciplinary core ideas, instructional decisions should include the use of many practices underlying the performance expectations (para. 1).

In other words, the NGSS performance expectations are designed to be the endpoint of an instructional unit, and if that unit was not explicitly designed for the NGSS and does not encompass the three-dimensions, there is little likelihood that the performance expectation will be able to assess what students learned in the unit. In the Project NEURON unit, the sole applicable PE that I could identify is HS-LS3-1: Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring. I believe that this performance expectation applies to portions of lessons three, four and seven.

In the next section, my critical friends' reflections and validations recorded during biology PLC sessions will be qualitatively analyzed, the data will be coded for a priori themes, and an analysis of the data surrounding issues and tensions concerning NGSS implementation will ensue.

Phase II Self-Study Critical Friends Reflections and Validations

The science department in the school district where I teach is at the beginning of its science curriculum adoption cycle. The start of the curriculum adoption cycle that aligns with the district's implementation of the NGSS is a welcome coincidence. This opportunity gives the secondary science teachers in our school district the opportunity to pilot new materials during the next school year which claim to align with the NGSS. However, tensions related to the adoption process were found to exist, and these tensions frequently emerged during discussions that occurred during our Professional Learning Community (PLC) meetings that biology teachers attend four times a week.

Data analysis. A qualitative analysis was conducted of conversations concerning implementing the NGSS that occurred during nine (PLC) meetings between myself and my critical friends during phase II of the study. Angela and Joan, my critical friends in this study, and I met on seven occasions during phase II of the study. The fourth biology teacher in our department returned from maternity leave, but her teaching schedule had changed, prohibiting her from meeting with us during PLC meeting time.

As in phase I of this study, a priori codes were developed before initial coding. As mentioned earlier in this study, a priori, or pre-set codes, can come from a range of sources in a study such as research questions, previous research that has been conducted, questions the researcher has concerning the topic of discussion, or the researcher's gut feeling about the data (Taylor & Gibbs, 2010). The digital recordings of conversations that occurred during the PLC meetings were transcribed, and the data was scanned for words, phrases, and patterns related to my a priori codes. These initial, level 1 codes, are labels that I connected to short sequences or phrases in the text that I analyzed. Table 14 lists the pre-set, a priori codes used in phase II.

Table 14

Initial Level 1 A Priori Codes and their Descriptions

A Priori Coding Category	Description
Model NGSS curriculum aspects	What aspects of a model NGSS curriculum are important to members of the biology PLC?
Performance expectation tensions	What concerns about the NGSS performance expectations emerge during our PLC conversations?
Curriculum alignment tensions	Are tensions about the alignment of the NGSS apparent during our PLC discussions?

After transcriptions of the PLC discussions had been made, instances of the initial level 1 codes were identified and selected in the transcripts using the comment feature in Microsoft Word. The codes were then categorized by highlighted color and identified by critical friend names during level two coding in the phase II coding table (Appendix N). The level two codes were then categorized and divided into the themes and sub-themes during level three coding which is shown in Table 15.

Table 15

Primary and Sub-Themes Recorded from Phase II PLC Transcriptions

Primary categories (themes)	Sub-themes related to primary themes
Model NGSS Curriculum	Curriculum characteristics. • Three-dimensions present • Varying science practices • PE's connect to activities • Model use • Summative assessments present • 3D learning identified in lessons • Varied assessment types • Scoring rubrics present

Table 15 Continued

Primary categories (themes)	Sub-themes related to primary themes
Performance Expectation Tensions	Making sense of PE's • PE's set • PE's purpose • PE's assessment role • PE's restrictive/narrow • PE's flexible/differentiate
Curriculum Alignment Tensions	Curriculum alignment issues • EQuIP rubric alignment • Curriculum alignment tensions • Curriculum alignment timeline/pilot • Curriculum alignment differentiation • Curriculum alignment uncertainty

Theme: Model NGSS Curriculum Characteristics.

The adoption of a curriculum that incorporates all three dimensions of the NGSS is crucial to the success of this science education reform. The scarceness of curricula that aligns with the NGSS was mentioned earlier in this study, but more recently, publishers have started releasing increasing numbers of instructional materials that claim to align with the three dimensions of the NGSS. During our PLC discussions, the topic of curriculum adoption was a frequent topic of conversation. Our PLC members had concerns about the future adoption of an NGSS aligned curriculum by our school district, and our discussions focused on the desirable characteristics that such an aligned curriculum should possess. I refer to a curriculum that has claimed full NGSS three-dimensional integration as a "model curriculum." The newly released STEMscopes curriculum (Accelerate Learning, 2016) is considered a model NGSS curriculum by the biology PLC members, and it is a top contender for NGSS adoption. The STEMscopes website contains science lessons which can be selected by disciplinary core idea, or by NGSS standards, and it uses the 5E lesson planning model.

Are the three dimensions present? One of the themes that became evident during coding of the PLC meeting transcripts was the utter necessity that the three dimensions be integrated into the curriculum that we adopt. During our discussions, and after closely examining the STEMscopes curriculum, the biology PLC members agreed that its lessons integrate the three dimensions of the NGSS. For example, STEMscopes integrates 3D learning into the biodiversity and environmental change lesson that we explored. We found that the lesson shows the integration of a science practice, a crosscutting concept, disciplinary core ideas, and uses a performance expectation for evaluation.

Varying science practices. During our discussions about what a model NGSS curriculum would look like, we all agreed that a variety of science practices should be evident in the unit. Joan (personal communication, January 2017) brought up this concern when she said:

> I'll pull up the cell division STEMscopes. On the homepage of the scope, for this curriculum, it lists the performance expectation. This one is HS-LS-1 through 4. The student is expected to use a model to illustrate the role of cellular division, mitosis, and differentiation in producing and maintaining complex organisms. I remember looking through the scope, and they do that. That's not the only thing they do. They do research about mitosis and the different purposes of mitosis.

This example shows how science practices are integrated into in this model curriculum.

PE's connection to activities. In a model NGSS curriculum, the biology PLC decided that a disconnect should not exist between the curriculum and the performance expectations. In fact, we agreed that the performance expectations should guide instruction as they are meant to be the endpoint of instruction. Joan (personal communication, January 2017) described the connection that she noticed between the performance expectation and a lesson in STEMscopes when she said: “So the very first activity after the hook, and after they do research, their first activity is: Students will model how cell division creates a complex organism. So, that’s one of their main activities to meet that PE.”

The use of models. During a survey of the STEMscopes lessons, the biology PLC noticed the use of model creation. I wondered whether the model utilized in the lesson involved the practice of developing an initial model at the beginning of the unit, and then required students to reconsider their original model throughout the lesson or unit, and then to revise their models. Discussing an example that we found in one lesson, Joan (personal communication, January 2017) stated that:

> This is not a before and after kind of thing. It’s a one time, one use model. There’s a parallel between modeling in class and modeling in science, and we teach kids that we can make changes to the model as new information is discovered.

A more thorough evaluation of the model unit would need to take place to determine how extensive model development is used in the STEMscopes lessons. We plan on making that assessment during the next school year when the unit is in the pilot phase.

Three-dimensional and varied summative assessments. The inclusion of well written summative assessments that are aligned to the NGSS in the curriculum adoption would greatly help biology teachers to align their classrooms to three-dimensional learning. During the PLC’s evaluation of the STEMscopes curriculum, we were pleased to find that summative assessment questions were integrated into each unit. Joan (personal communication, January 2017) searched the STEMscopes unit, and she found that “in each scope, they also have a performance expectation assessment task.” We asked her to open the performance expectation task in the lesson on her computer, and she declared that:

> For cellular differentiation and reproduction, they call it Performance Expectation Assessment Task, *PEAT*, and it's under these two modules or scopes. This is the cell division scope, and kids would have to do the essentials of life scope as well. So, this is how they outline it; the science and engineering practices are listed in this assessment, DCI's are listed, PE's, Crosscutting Concepts.

We took a closer look at the details of the *PEAT* task, and Joan reported that the assessment task states that:

> Students will design a sequence of events, comic strip, for example, beginning with DNA and a zygote to describe the role of mitosis and differentiation in producing and maintaining complex organisms. Students will then use their knowledge to construct an explanation for how DNA determines the structure of proteins and traits. A comic book, storyboard, or short story.

I commented that this assessment task appears to contain all three-dimensions of the NGSS, and we agreed that this was a 3D assessment task. We also appreciated that the curriculum writers included differentiation into the assessment question. As we examined the STEMscopes curriculum assessments, we also found further evidence of variation in the types of assessments used in the units. There were multiple instances of claim, evidence, and reasoning (CER) activities, and we were glad to see that multiple-choice questions were included in unit assessments. Our discussion then turned to the value of multiple choice questions. Joan and Angela made the argument that multiple-choice questions are used extensively both in college and in standardized testing. I made the point that students should have plenty of practice answering multiple-choice questions as this testing technique is one of the "gatekeepers" in their access to higher education, and is used in both the ACT and SAT entrance exams.

Scoring rubrics. Our school district requires that scoring rubrics be made available to students for all summative assessments, so the inclusion of scoring rubrics in a model NGSS curriculum is preferable. Joan found that each unit assessment had an attached scoring rubric, but upon closer look, Angela discovered that the rubrics looked somewhat generic as they lacked the detail that we were required to include in our current unit and assessment rubrics.

Theme: Performance Expectation Tensions: Making sense of PE's

One of the tensions that came up repeatedly concerning the NGSS during our biology PLC meetings surrounded the performance expectations. Per the definition of performance expectations (PE's) found on Nextgenscience.org:

> The NGSS is not a set of daily standards, but a set of expectations for what students should be able to do by the end of instruction (years or grade-bands). So, the performance expectations set the learning goals for students, but do not describe how students get there (NGSS Lead States, 2013, para 1).

The tensions surrounding the biology PLC's understanding of the NGSS performance expectations are negotiated in the next section.

Are performance expectations set? One of the questions that arose during the biology PLC's discussions was whether the NGSS performance expectations (PE's) are set. By this, we wondered whether the PE's could be renegotiated in their science practice emphasis. When we read the life science performance expectations, we felt that they were extremely narrow in their learning goal expectations. For instance, the NGSS life science performance expectation HS-LS4-2 states:

> Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable

> genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment (NGSS Lead States, 2013, para. 2).

We questioned whether a performance expectation such as the one listed above could be addressed using a different science practice such as engaging in argument from evidence, or asking questions and defining problems. In other words, we wondered why the writers of the NGSS settled on the science practices that they did in each performance expectation. In one conversation, I asked Joan (personal communication, January 2017) if she thought that we could switch around the different science practices in the performance expectations, and she responded with the question “how much wiggle room or freedom do we have?” I answered that I was not sure.

Later in our conversation, Angela (personal communication, January 2017) stated: “I feel like the intention is that we could always add more, but that you shouldn’t remove what they’ve put in, which I’m not sure I agree with.” We finally decided that because the performance expectations were written specifically to assess the life science content, that we should make every effort to use them in an assessment the way they are written. Then later we could add additional science practices if we feel that it was necessary.

The purpose of performance expectations. On one occasion during a biology PLC meeting, we debated about the purpose of the NGSS performance expectations. Joan (personal communication, January 2017) stated that she thought that maybe the PE’s were designed “to give the teachers some direction, because what would the verbiage be without specificity?” We finally decided that the performance expectations signify what students can do, so they are there to help guide student assessment. This conclusion aligns with the what is intended in the NGSS when it states that:

> Performance expectations are the assessable statements of what students should know and be able to do. Some states consider these performance expectations alone to be “the standards,” while other states also include the content of the three foundation boxes and connections to be included in “the standard” (NGSS Lead States, 2013, para 3).

The PLC group was unable to determine the State of Illinois’ position on whether performance expectations are the standard, or whether the NGSS’ standards are a combination of the performance expectations with the three-dimensions as are described in the *Framework* (2012).

Performance expectations role in assessment. The role of performance expectations in the assessment was considered during our biology PLC meeting when I asked if the other members thought that when we were all three eventually teaching under the NGSS if we would be using the PEs as our guidelines for our assessments. During our preview of the STEMscopes biology curriculum, we could get a clearer picture of how a well-designed unit could use the NGSS PEs as the basis for unit assessment questions. For example, in the Genetics “scope” on the STEMscopes website, https://www.acceleratelearning.com, the summative assessment question for the unit states:

> Students will ask questions that clarify the role of DNA in inheritance and explain statistically how traits are distributed within a population. Students will then make a claim supported by evidence that variation within a population results from meiosis or natural and environmental mutations (Accelerate Learning, 2016, para 3).

Students are asked to complete the performance expectation assessment task (PEAT) after they have completed all the modules required in the unit. This assessment question, like all the others that we reviewed in the STEMscopes curriculum, represented a three-dimensional test of student learning and included all three-dimensions in the question. Having this model assessment available to us at the beginning of the curriculum adoption cycle will have relieved the tension we felt surrounding performance expectations and assessment.

Performance Expectations are restrictive and narrow. We were unable to come to an agreement as to what several of the biology PLC members felt was a narrow and restrictive focus found in the NGSS life science performance expectations. At one point in our conversation, I questioned how the writers of the NGSS decided that a claim, evidence, and reasoning (CER) would be the best fit in one performance expectation and not another. My contention was why students should be so limited in their ability to express their mastery of a concept? For instance, why could students not collect and analyze data for a concept instead of completing a CER? Angela (personal communication, January 2017) took an interesting stance on this issue when she stated that:

> I feel like the intention is that we could always add more, but that you shouldn't remove what they've put in, which I'm not sure that I agree with. If there are things that I have to remove for differentiation purposes. I guess you could say that we're going to scaffold it, or that we're going to provide them a framework, we're going to provide them with more supports, but when does that assessment completely leave the intention of the assessment in the first place, when I just provide more and more support to differentiate it, instead of saying I'm going to choose something else as the performance expectation assessment.

> So, I wonder if it's restrictive in that the idea that I am going to do a CER instead of doing research, or a model.

Angela's point was well taken, as we agreed as a PLC that if the student population that we were teaching was responding better to a certain assessment strategy, that we should have the freedom to adjust our exams accordingly.

Performance expectations' flexibility and differentiation. The issue of flexibility in adhering to performance expectations became a point of contention. In a discussion about performance expectations, Angela (personal communication, January 2017) made the following argument:

> I think that with any one of the PE's there are any number of ways we could attack it. That's why the other day when we were talking about some of these, and that we should be willing to throw out some in place of the other activity that would work better with the particular group of kids that you're working with this semester.

While all the biology PLC members felt that there should be some degree of flexibility and differentiation when negotiating the performance expectations, Angela (personal communication, January 2017) was the most vocal in support of her autonomy when she stated that:

> If there are things that I have to remove for differentiation purposes, I guess you could say that we're going to scaffold it, or that we're going to provide them a framework. We're going to provide them with more supports, but when does that assessment completely leave the intention of the assessment in the first place, when I just provide more and more support to differentiate it, instead of saying I'm going to choose something else as the performance expectation assessment? So, I wonder if it's

restrictive in that the idea that I am going to do a CER instead of doing research, or a model.

After our discussions, which brought to surface issues and tensions that we were feeling as a group surrounding the NGSS performance expectations, we decided as PLC to follow the PE's as "the assessable statements of what students should be able to do," as is described in the NGSS description of performance expectations (2013, para. 8). However, we also decided that if circumstances arise where we believe that other science practices could better serve our student population, then we would make the decision as a group to consider the change.

Theme: Curriculum Alignment Tensions and Issues

This issue of whether the curriculum that the school district would soon adopt closely aligns with the NGSS led to several discussions during our biology PLC meetings. These discussions revealed underlying tensions that the PLC members were feeling concerning curriculum alignment, and they provided an opportunity to express our views on several issues.

EQuIP rubric alignment. The educators evaluating the quality of instructional products (EQuIP) rubric version 3.0 "provides criteria by which to measure the alignment and overall quality of lessons and units with respect to the Next Generation Science Standards ("EQuIP rubric for lessons & units: Science," 2016, para. 1). During one of our biology PLC discussions, I wondered if we had a pilot curriculum that did not align to the NGSS after failing an evaluation using the EQuIP rubric, what our reaction would be as a PLC. Angela (personal communication, January 2017) had a controversial opinion of NGSS alignment when she stated:

> I feel like that one of the things we have to be prepared to do is say that not every ounce of the curriculum is going to be aligned to the standards. That's okay. The state has adopted the standards, but the district is choosing the curriculum, right? So, especially if

> we're doing the two-year plan, then all standards for all students just isn't going to happen.

Angela's view that the practitioner's voice was absent from the curriculum selection process revealed tensions that I believe many teachers are experiencing during the NGSS implementation process. Joan (personal communication, January 2016) responded to Angie's comment by stating "yep, I think we do our best! It's not going to be perfect."

Curriculum alignment tensions. I contend that the issues which emerge during discussions among our biology PLC group give its members a voice. Paying attention to these tensions as they arise opens the door for continued discourse which can elicit change. One issue that we discussed was curriculum alignment to the NGSS. Angela (personal communication, January 2017) expressed concerns about teaching under and NGSS aligned curriculum when she declared:

> So, we have to go, okay, and we're going to hit it (the NGSS curriculum) and teach as much as they want us to teach. But understanding that these are our students, and our district, and with this group of kids, you can still teach well traditionally. Kids can still learn, and just because it doesn't pass this rubric, it doesn't mean that it's not good, it's just not what they're saying matches to the NGSS manner of teaching.

The concern we had is that teachers will be forced to abandon some of the traditional teaching methods that they have embraced for many years, in place of a curriculum that they are unsure of. The assumption is that conventional methods hold some sort of value and that the value in the new teaching methods still has not been determined.

Curriculum alignment timeline and pilot. Tensions continued to emerge during discussions we had concerning the timeline proposed by the school district for piloting the new

NGSS curriculum, and whether teachers would have the autonomy to introduce NGSS lessons gradually. During one conversation, I mentioned that I had read a recent article which suggested that teachers begin the transition to three-dimensional teaching by slowly integrating NGSS lessons into their curriculum (Thakkar, 2015). Joan, the fourth-year teacher in the biology PLC who has received the most training in the NGSS, and is currently piloting STEMscopes lessons on her own, was asked by Angela if including some of the labs that we currently use would "mess up the rest of the lesson?" Joan (personal communication, January 2017) replied:

> So far it hasn't! I did the hook lesson for cell division after the hair model, and it was great. And now in my next lessons that may not be STEMscopes, I can still make connections to the STEMscopes lesson and the original models that we made. So, I'm pleased with it so far! So far as traditional teaching, I'm only still in my fourth year; I'm also going to be doing the onion root tip lab like every other year.

While some of the labs that we currently use in our biology department have the potential to be modified to fit in the newly adopted curriculum, it is my contention that we should pilot the new curriculum using the activities it provides that have been designed around the NGSS. During the pilot, gaps in science practices will also be revealed, and then we can research NGSS designed labs and activities to fill in the gaps.

Curriculum alignment: differentiation and uncertainty. Differentiated instruction "allows all students to access the same classroom curriculum by providing entry points, learning tasks, and outcomes tailored to students' learning needs" (Watts-Taffe et al., 2012, p. 304). In our PLC discussions, issues concerning differentiated instruction were regularly raised, as all three of us teach both academic and accelerated (honors) level biology classes. We all had concerns about whether a student-centered curriculum as is suggested by the NGSS will work in our academic classes. Students in these classes have generally had poor success in middle school science, and many students with special needs and are enrolled in co-taught sections. The structure inherent to traditional teaching methods allows for more teacher control of the learning environment in academic classes, and it is my experience that group work with at-risk students is not always as successful due to students have a difficult time staying on task and working well together. Angela (personal communication, January 2017), who currently teaches two academic biology sections, expressed her opinion that: "Part of what makes you a good teacher is your ability to change and adjust to students' needs. That becomes harder for me if everything I'm doing is brand new all year. Then am I teaching this right according to this book, or these people?"

Joan responded to Angela's comment by saying, "versus, how does this group of students learn? It becomes more about the lesson than the lesson being responsive to the students." Both Angela and Joan's comments reflect the tensions that teachers face when the curricular design does not meet the perceived needs of all students. The assumption is that the some of the traditional methods that are still being embraced provide more flexibility in differentiating instruction than the "new" methods that they are unsure of. In the case of the NGSS, negotiating a student-centered curriculum with classes that need a more teacher-centered structure is a scenario that will soon play out in our science department.

Phase II Self-Study Student Work Analysis

In the article: *What makes us tick…tock? Using fruit flies to study circadian rhythms* (Talbot & Hug, 2013), the authors describe how Project NEURON designed a unit "that combines scientific practices identified in the *Framework* and *NGSS*; core biological ideas, such as Genetics and Animal Behavior; and crosscutting concepts, including Cause and Effect, Structure and Function, and System Models" (p. 37). During enactment of the Project NEURON unit, I monitored student work for evidence of three-dimensional learning.

Model creation. In lesson two of the what makes me tick…tock unit, on page one of the NetLogo investigation: How do temperature and light affect the fruit flies' activity levels? worksheet ("Novel education for understanding research on neuroscience," 2016), students are asked to answer the question:

> How do sleep/wake cycles function? Use information from Lesson 1 and prior knowledge to draw a diagram or picture (i.e. model). Be sure to explain your model using 2-3 sentences.

In the first example of student work, the group provides a written description explaining their model, but the description is not very detailed. However, in Figure 17, the group shows their understanding of several of the concepts related to sleep/wake cycles, and the drawings are very creative.

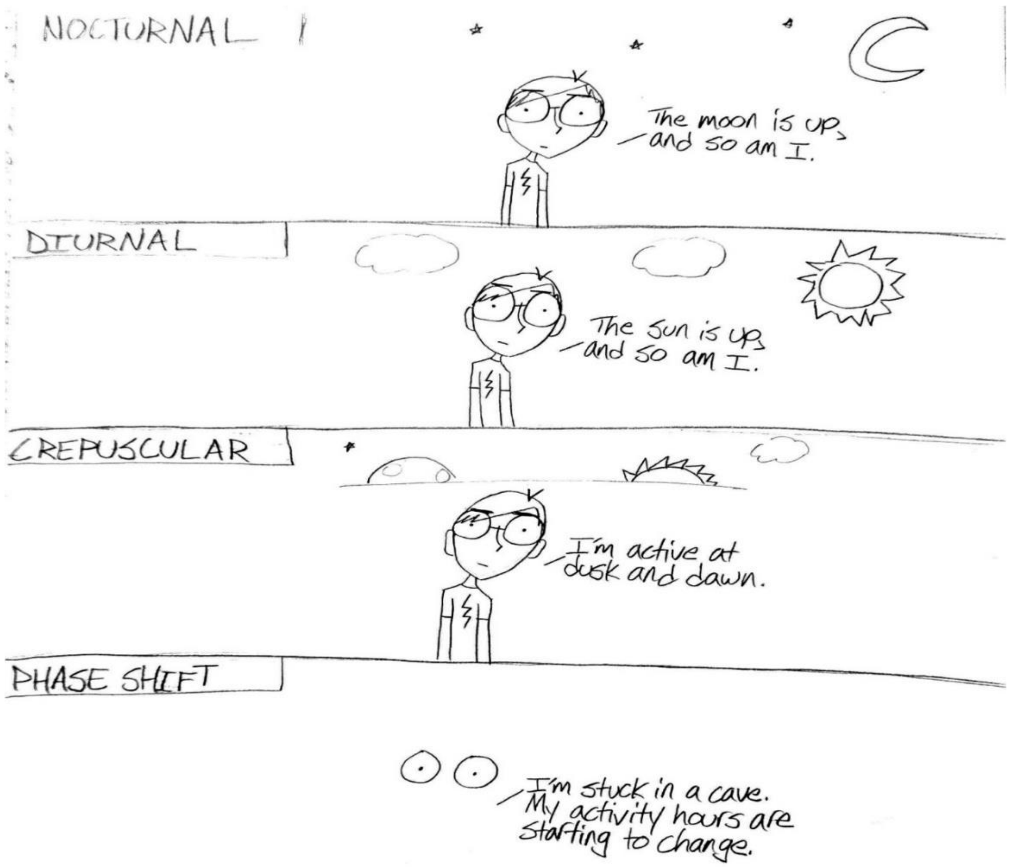

Figure 17. Group one's model of circadian rhythms. This model shows a cartoon-like approach to model development.

Group two's model of circadian rhythms is illustrated in Figure 18. Group two's model is better developed than group one's, as it contains much more detail. The students have included the concepts of owls, larks, and hummingbirds in their model, and they have also introduced the idea of zeitgebers, or environmental cues.

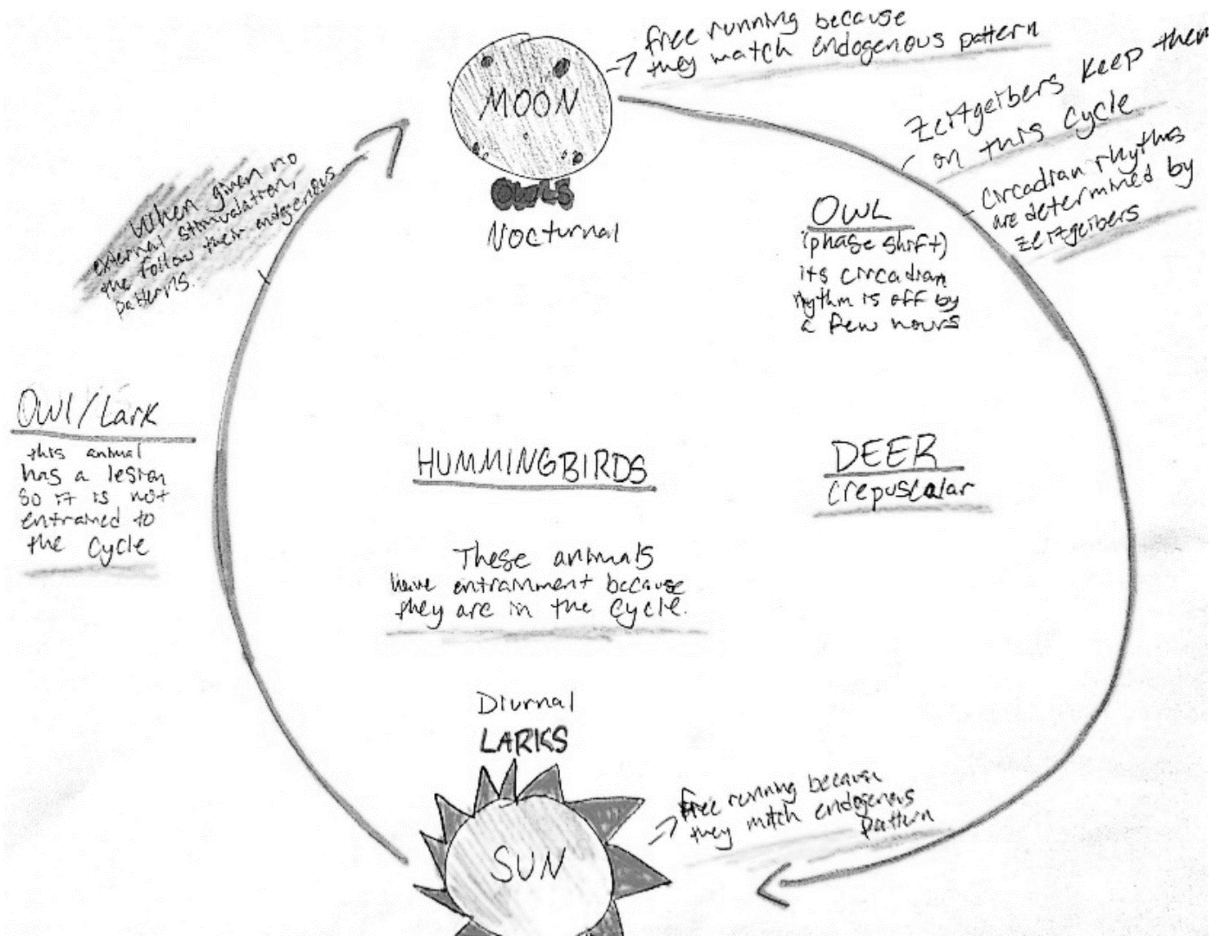

Figure 18. Group two's model of circadian rhythms. This model shows a cyclical approach to model development.

Do these models represent the three-dimensional learning as it is described in the *Framework* (National Research Council (U.S.). Committee on a Conceptual Framework for New K-12 Science Education Standards., 2012)? I contend that if students are asked to create a model, but are not given the opportunity to revise their models, then students are simply answering a question. However, students do use the science practice of developing and using models, the crosscutting concept of cause and effect, and the core idea of animal behavior in their model creation.

Model Revisions. A *Framework for K-12 Science Education* (2012) suggests that by the time students graduate from high school, they should be able to:

- Construct drawings or diagrams as representations of events or systems
- Represent and explain phenomena with multiple types of models and move flexibly between model types when different ones are most useful for different purposes.
- Discuss the limitations and precision of a model as the representation of a system, process, or design and suggest ways in which the model might be improved to better fit available evidence or better reflect a design's specifications. Refine a model in light of empirical evidence or criticism to improve its quality and explanatory power.
- Use (provided) computer simulations or simulations developed with simple simulation tools as a tool for understanding and investigating aspects of a system, particularly those not readily visible to the naked eye.
- Make and use a model to test a design, or aspects of a design, and to compare the effectiveness of different design solutions. (National Research Council (U.S.). Committee on a Conceptual Framework for New K-12 Science Education Standards., 2012, pp. 3-20)

Part of the process of constructing models is in their revision. It is crucial that students develop the ability to construct models that help explain the phenomena they are investigating and then be able to revise their models when they are exposed to new evidence (Krajcik & Merritt, 2012). The next two examples of student work illustrate the process of model revision after students explored the effects of different temperatures on the activity of fruit flies using the NetLogo computer simulation. Students were asked to revise their initial models to reflect what they had learned about the effects of temperature on circadian rhythms after they had tested their original hypotheses using the NetLogo fruit fly computer simulation.

Figure 19. Group one's revised model of circadian rhythms. The original cartoon is modified to include the effects of temperature on the sleep/wake cycle.

While group one's model revision is not perfect, it certainly is creative as is shown in Figure 19. The students use the same cartoon theme to illustrate their model, as they did in the initial model, only this time they include the three hypotheses that they had developed about the effects on an organism's circadian rhythms with regards to a shift in temperatures. I realized that the act of creating an isolated model is not a three-dimensional process, but that the revisions of models as students are exposed to new concepts and change their ideas in the revisions embrace the intent of the NGSS.

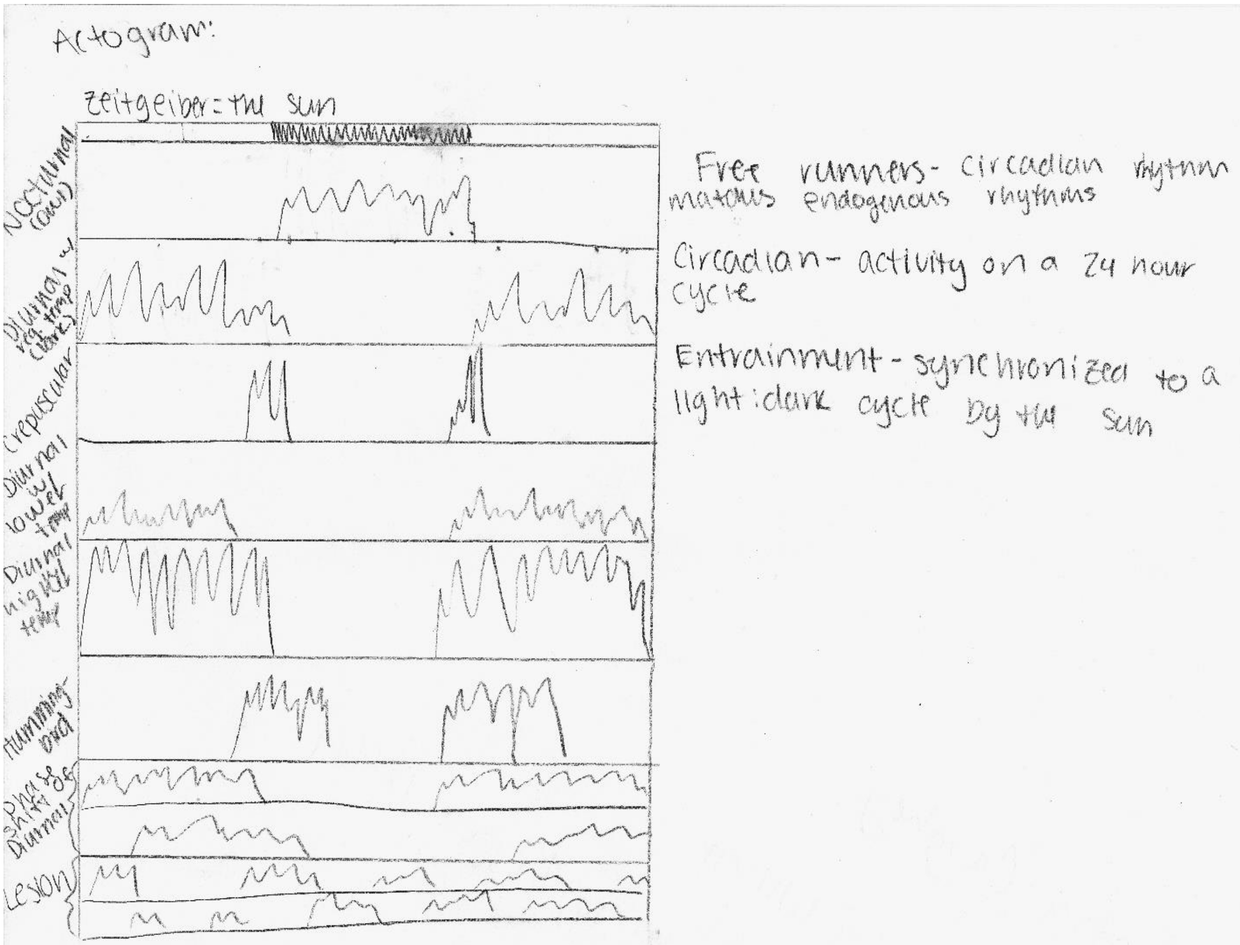

Figure 20. Group two's revised model of circadian rhythms. An actogram-style of model creation is used in the model revision.

Figure 20 shows that group two's model revision is much more complex than group one's revision. When I searched for group two's revised model in a stack of papers, I thought I had selected the wrong group's revision when I came across it, as it was so strikingly different from their original model. It was interesting to see how the group went from a more systematic approach initially to the question of circadian rhythms and how they tied their new knowledge of actograms into the revisions. I approached the group and asked them why they had made such a dramatic shift in the representation of their model, and the group claimed that they thought it would better portray all of the different concepts that they were trying to understand than in the first model they had created. While there are some inaccuracies in the model's actograms, students do show an understanding of time shifts and the effect of lesions on circadian rhythms. It seems to me that the students were renegotiating the explanatory power of the model.

I contend that both model revisions show growth and development in student understanding of concepts, which is the intent of model revisions, albeit group two seems to have a more detailed understanding of the content than group one. I believe that students are negotiating changes in how they view circadian rhythms in the best way they can as a fourteen-year-old freshman. The shift in model types between the initial model and the revised model that group two presents make me assume that they were renegotiating how to best express their understanding via model creation.

Later in the unit, student groups were asked to revise their models a third time to show how they thought genetics and mutations influenced sleep/wake cycles as is illustrated in Figure 21.

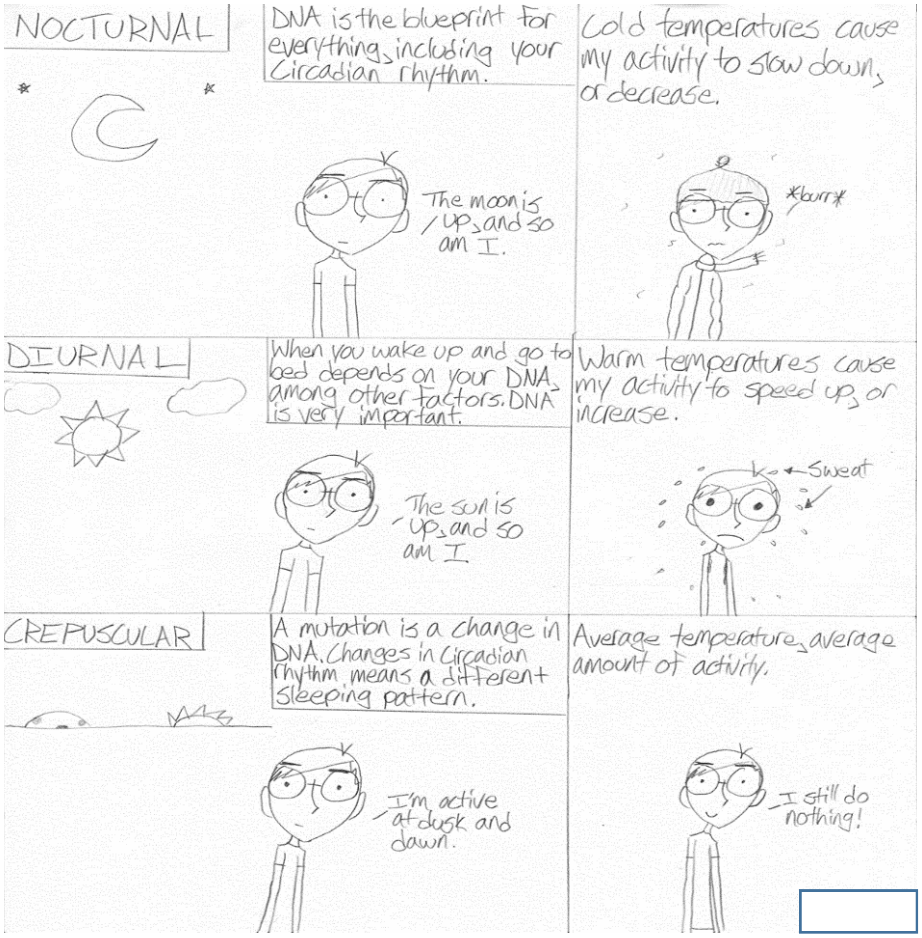

Figure 21. Group one's third revised model of circadian rhythms. The cartoon has been further modified in this model revision to include the concept of mutation influence on circadian rhythms.

Group one decided to revise their third model of circadian rhythms by adding to their second revision. Students were asked to include what they thought the impact of DNA, genetics, and mutations had on sleep patterns. Group one included text boxes to their drawing showing that they have a basic understanding of the concept. In my analysis, I believe the crucial aspect of group one's model revision is the act of revision itself. This is the first time I have asked students to make a series of revisions to models of biological phenomena that they had created, and I assume that this was the first time many of my students had been asked to develop and revise models in their science classes. Group two's third revision of their sleep/wake model in shown in figure 22.

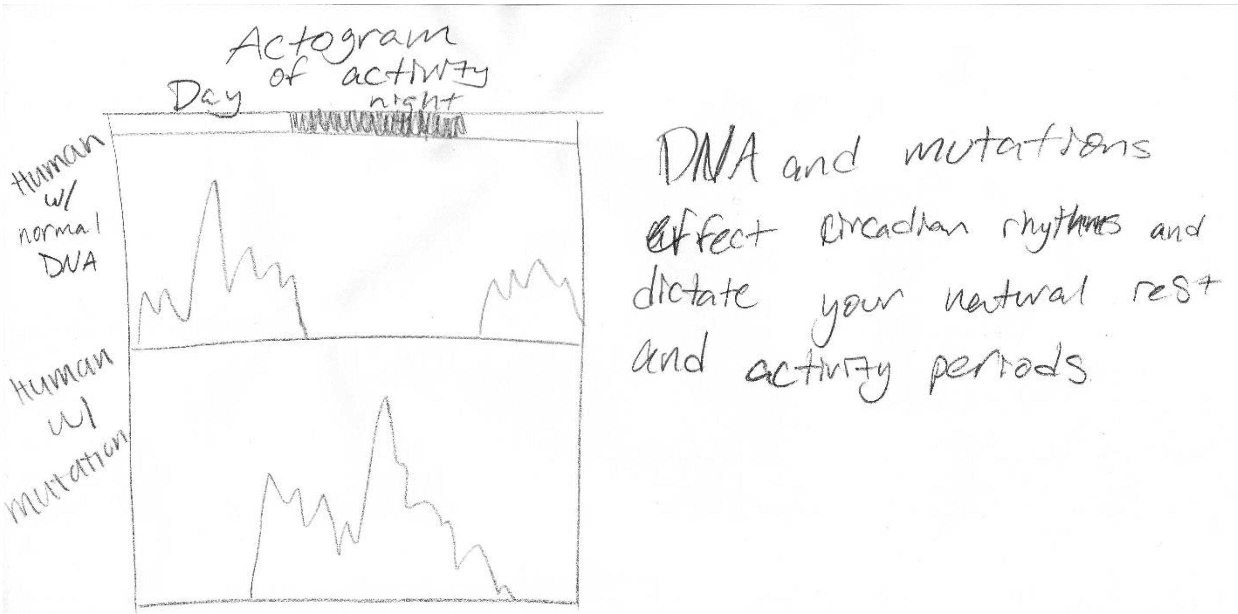

Figure 22. Group two's third revised model of circadian rhythms. The actogram theme continues in the third model revision to include the concept of DNA mutation effects on circadian rhythms.

In group two's third revision of their model that reflects their understanding of the influence of DNA and mutations in sleep/wake cycles, they chose to draw a new revised model, instead of adding on to their first or second model. Like their second model revision, group two used an actogram to present their model. While the model is limited in content, group two's model does show that they understand that sleep/wake cycles are controlled genetically and that a change in DNA, or mutation, can impact the cycle.

I contend that the practice of model development and revision constitutes three-dimensional learning. Earlier in phase I, the claim was made that the POGIL assignment questions constituted 3D learning, but then I reconsidered that assertion and realized that 3D learning was more than just answering isolated questions in a workbook. I now believe that 3D learning is a *process* that involves continued and prolonged use of science practices to explore science content with the use of crosscutting concepts, and agree with researchers that contend models "have value because they provide students with connections and intellectual tools that are related across the differing areas of disciplinary content and can enrich their application of practices and their understanding of core ideas" (National Research Council (U.S.). Committee on a Conceptual Framework for New K-12 Science Education Standards., 2012, p. 233).

The differences between the traditional teaching approach and the student-centered approach just described reflects the significant pedagogical shift inherent in three-dimensional learning. The model revision process provided in the Project NEURON unit was the first instance in my teaching career that students have created and made multiple revisions to a model. It was interesting to observe the enthusiasm that students exhibited during the model revision process. Likewise, students were engaged in discourse during the process that was unlike any discourse I have observed during my tenure as a teacher. The conversations were intense and argumentative as students negotiated how they would express the changes in their conceptions through model revisions, and then translate their collective ideas on paper. The process seemed to give students a voice while grappling with the changes in their conceptions. The feeling that I experienced as a teacher during the model revision process was an 'aha' moment for me. I finally understood the three-dimensional learning process. While I do value the control that I have had over all aspects of teaching and learning in my teacher-centered past, the experience of students truly negotiating their way through model revisions using the three dimensions trumped my long held traditional methods. In the next section, video and audio data collected during the study will be used to describe a class portrait of a student-centered class period during the self-study.

Phase II Self-Study Class Portrait

Class began on this day much as usual. As students filed into the classroom, I greeted them with a smile and asked them to turn their homework in the tray on the front table. I had everything prepared for the lesson on the presentation computer as was suggested in the Project NEURON curriculum. A picture of a lark and an owl were displayed on the Smartboard. My grade book was open with the seating chart on top as I always do to take attendance. I felt a little apprehensive as this was my first day teaching with the Project NEURON materials.

My eighth hour accelerated biology class had grown considerably in size since the first semester. Four of my accelerated students had moved to different biology sections because of scheduling conflicts over the holiday break. I do not like to lose any of my students at semester because, at this point in the year, I know them all very well and have developed relationships with my students. However, I gained six new students from other biology classes at the start of the second semester, giving me a total of 30 students in my eighth-hour class. The feeling of the class had changed dramatically from the first semester. Thirty students in a lab-based science class are quite a challenge, especially when it comes to setting up and running labs and activities. As I looked out over the classroom, I noticed that all of thirty of the desks were full.

After taking attendance, I formally greet the students; then I go over the schedule for the week that was posted on the whiteboard. This was on a Monday, and it is my routine to give students an overview of the week. I began the lesson by asking students questions that were suggested by the Project NEURON curriculum to get them thinking about the phenomenon that drives the storyline in the unit. I asked the students how many of them were feeling sleepy now, and nearly three-quarters of the students raised their hands. I was shocked! I have always been curious how I can be so much older than them, and much less tired. I commented to the class that although I realized that they looked tired, I didn't think that it would be so many of them would raise their hands.

Continuing, I asked how many of the students had to use an alarm clock to wake up for school in the morning. Only five students raised their hands in response to the question. Once again, I was surprised. I assumed that most of the students would use alarm clocks to wake up in the morning. When I asked how many students had their parents wake them up for school in the morning, almost half of the class responded. I had no idea that they relied on their parents to wake them up at their age. Finally, I asked of those who didn't respond, how many of them woke up on their own without any assistance, and three students responded. One of those students stated that he wakes up at precisely 6:15 am every morning on his own. I was impressed that he had such an accurate and reliable internal clock, so I asked him why he thought he could do that, and he said, "I don't know, I just do!"

I used these questions to help students think about their sleep-wake cycles. I directed the students' attention to the pictures of the owl and lark that I had displayed on the Smartboard, and I asked the class how we could use these animal examples to describe the different sleep patterns found in people. Students were eager to answer, and we discussed what lark and an owl were with respects to their sleep patterns. One student responded that owls were "night people" and that larks were "day people."

In the next part of the lesson, I challenged the students to create survey questions that they could use to interview their classmates to find out who were the larks, and who were the owls. I gave the students the owl and lark survey handout that came with the Project NEURON curriculum. The students were told that they had 10 minutes to work in their groups to develop five survey questions. I gave them some suggestions as to some of the types of questions they could use to help develop their surveys. Next, I asked the students to break up into groups of between 3 to 5 students to develop their survey questions. I let the students know that after they developed their questions, that they would then have 10 minutes to find three classmates and interview them to determine whether they were larks or owls and that they would need to record their results on the whiteboard at the front of the classroom and fill in a table that I had prepared.

The students seemed excited and ready to interact with each other. Students quickly spread out around the classroom and in the lab area. They formed groups on their own and immediately began talking enthusiastically about the survey questions. I set a 10-minute timer on the smartboard and started the countdown. As I walked around the classroom, the students were excitedly discussing what they would ask their classmates when they interviewed them about their sleep patterns. Student groups developed their survey questions much quicker than I anticipated, and when the timer counted down to five minutes left, I let the students know that their time was almost up, but most of the students had already completed developing their five survey questions. One group of students asked me if they could interview members of their own group, and I told them that they could each interview two of their own group members, but that they needed to find somebody external to their team to interview as well.

The classroom was loud and boisterous as the interviews began taking place. When the timer finally went off, students were already well underway interviewing each other. The classroom seemed like controlled chaos. Students were moving all around trying to find students who had not yet been interviewed, and it was loud. Eventually, after about 10 more minutes of interviews, students began trickling up to the whiteboard at the front of the classroom where they began writing tally marks of their results from the interviews. Once it seemed like most the students had recorded their results on the board, I informed the students that they should head back to their seats so that we could discuss the survey results. There were a few stragglers back in the lab area that I had to ask to head to their seats, and then we began a discussion about why they thought that there were considerably more owls than larks recorded in the results. One student insightfully said that he was forced to be a lark just because he to get up for school each day, but he was really an owl. I explained to the students that it was very typical for there to be more owls than larks among college and high school students, and then asked them why they thought this was the case. One student responded by saying that he had a lot of demands on his time such as extracurricular activities and doing homework which forced him to stay late up late at night. I announced to the students that we would continue our discussion about owls and larks the next day when I noticed that there were only a few minutes left in the class period. I then asked for a volunteer to pass out the homework, and the bell rang.

The class portrait that I just presented represents a more student-centered classroom where the teacher assumes the role of a learning facilitator, and where the students are actively engaged in group discourse to achieve the goal of collecting and reporting data. Students seemed eager to develop their survey questions, and then to gather data about their friend's sleep patterns. The excitement in the classroom and the high noise level was in stark contrast to the highly structured and organized teacher-centered classroom that I normally run. I found that the teacher-centered part of me wanted to ask the students to tone down, but I resisted the urge to exert my control and let the experience evolve naturally. I reasoned with myself that as long as students stay on task and are learning three-dimensionally, that I was the one who needed to adjust my tolerances, although it may take some time until I am comfortable with the change in classroom dynamics. Is this what three-dimensional learning looks like? I believe that this class portrait represents a snapshot of the kind of learning that the NGSS was designed to produce.

Phase II Self-Study Concept Map and Tag Clouds

During the analysis of field notes data collected during phase II of this self-study, a concept map and tag clouds were created to help visualize aspects of instructional methods, general reflective comments, points of tension, and issues of control.

Phase II concept map. The concept map for phase II contrasts sharply to the concept map in phase 1. Figure 23 illustrates the cyclical nature of a student-centered classroom, versus the concept map in phase 1 which was unidirectional and teacher-centered.

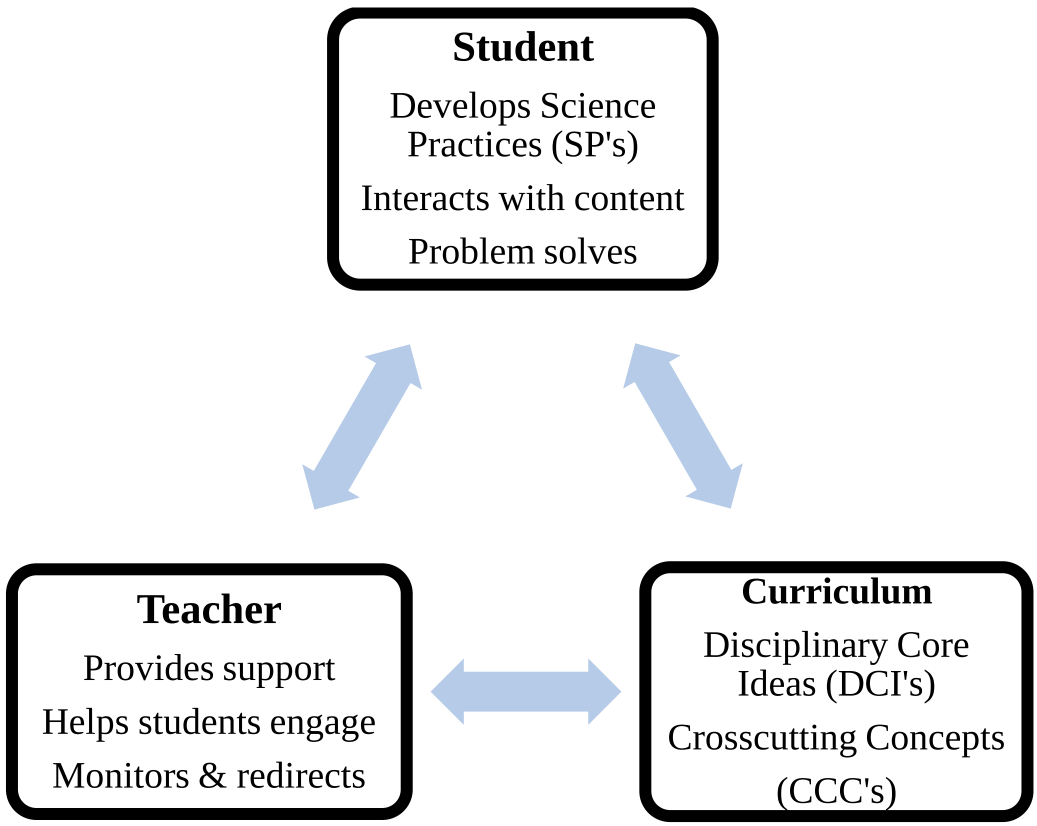

Figure 23. Phase II concept map: Student-centered learning. A cyclical interaction is shown between the student, the teacher, and the curriculum.

In contrast to the concept map in phase I of this study, the concept map for phase II shows how the interactions that take place in a student-centered learning environment are multidirectional. The students' role shifts in student-centered learning to one that is interactive with both the content and the teacher. The teacher's role shifts from one where the teacher is the sole purveyor of knowledge in teacher-centered learning, to one where the teacher monitors and directs student learning and provides support to students to help them engage with science practices, disciplinary core ideas, and crosscutting cutting concepts. I contend that it takes practice and time for the students to develop their understanding of science practices. In a recent article about student-centered instruction, the author states that:

> The next generation of model science instruction removes the teacher from the role of all-powerful distributor of knowledge. Instead, the teacher tunes the inquiry environment, adjusting student supports, helping students engage with materials in appropriate ways, and monitoring and redirecting where necessary. Students, for their part, develop and use the content with which they are interacting, hone their STEM skills and explain dynamic interactions through a system behavior lens (Vigeant, 2016, para. 5).

From the data that I collected in phase II of this study, the enactment of the Project NEURON unit provided me with the opportunity to experience a shift in my instructional role. My role shifted from one as the purveyor and distributor knowledge, who first presents phenomena, and then has students confirm the phenomena during labs and activities, to a role where students explore biological phenomena using science practices and then create and revise their models of the phenomena as they move through the instructional unit, and I provide them support and help them engage with the content.

Phase II Tag Clouds. In phase I of the study, I described how the use of tag clouds could be used to analyze word dominance in written discourse. Figure 24 shows the tag cloud generated after the general reflective comments in the field notes were inserted in the tag cloud generator, and the dominant words used in the field notes emerged.

Figure 24. Phase II tag cloud: General reflective comments.

Like the tag cloud in phase I, the word "student" is dominant in the field notes discussions, as was the case during the enactment of the traditional ecology II unit. However, the similarity between the phase I and phase II tag clouds ends there. It becomes evident that there is a major change in discourse during phase II, as words such as model, phenomenon, groups, collecting data, shift, disciplinary core ideas, and patterns, emerge in the tag cloud. I believe that the phase II tag cloud is a good representation of the shift that I experienced pedagogically from teaching a traditional unit to a unit that more closely aligns to the NGSS. During analysis, I noticed that certain words emerged which reflect science practices in the unit such as analyzing data, collecting data, patterns, analysis, asking questions, and disciplinary core ideas, all of which are connected to the NGSS.

The tag cloud shown in Figure 25 was created using data collected from field notes entries which concentrated on points of tension and issues of control during phase II. The predominance of the words "student," and "groups" is unsurprising, as discussions in the field notes tend to focus on classroom activities. The next dominant words in the tag cloud reveal some of the underlying tensions and issues recorded in the field notes. The words “time” and “rushed” were written extensively in the field notes, revealing concerns about time management, and unit completion. Other teacher oriented words emerge in the tag cloud. These words highlight tensions and issues related to control, a shift in instructional methods, and the teacher’s role were all about a student-centered classroom. The tag cloud shows concerns for how students were learning, thinking, gaining knowledge, and solving problems during my field note reflections in phase II. I believe that the use of tag clouds provides another lens by which a teacher using self-study can better see issues that occur in their classroom through a different lens.

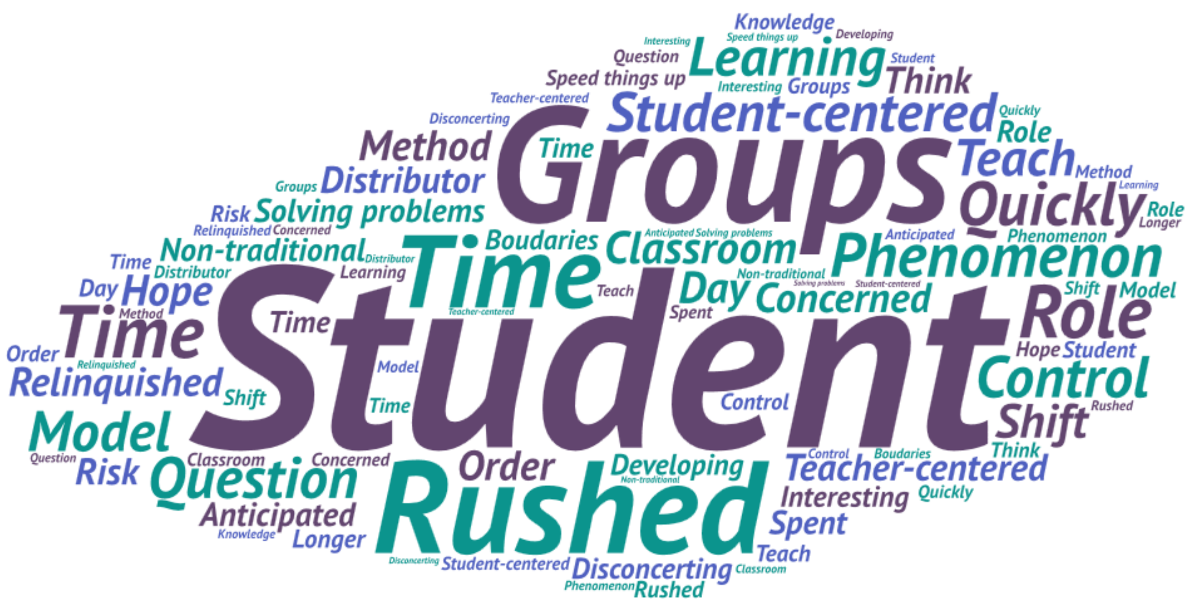

Figure 25. Phase II tag cloud: Points of tension and issues of control.

The tag cloud shows the prominence of words related to tensions and issues concerning students working in groups, feeling rushed through the curriculum, and other time constraint issues seen in the dominance of the words “quickly,” and “time.” I believe that because I was enacting this curriculum for the first time, that I was unsure about the material and had to read over each lesson multiple times. This process was reminiscent of when I was a new teacher and starting out from scratch when I would spend long nights preparing to teach a lesson that I was unsure of. This contrasts with the confidence that I feel when teaching biology lessons that are familiar with methods that I have perfected over my career. The words control, shift, risk, non-traditional, and disconcerting, all emerged from the field notes and were displayed in the tag cloud. I find that these words illustrate the concerns I had about stepping into the non-familiar pedagogical territory. I felt at certain points that the Project NEURON curriculum was highly scripted to the point that it felt unnatural following it. I had assumed that the unit enactment would come more naturally for me, but I now believe that because I was unfamiliar with the content, I was not as fluent and confident as I usually am when teaching material that I am familiar with. The use of tag clouds allowed the dominance of words to emerge from the field notes I wrote relating to the shift that I felt as a teacher assuming an unfamiliar role. The examples that I have described show how the use of tag cloud discourse analysis provides a method to which a teacher using self-study can better visualize issues and assumptions that occur in their classroom through a different lens.

Summary of Phase II Findings

During phase II of this self-study, an analysis of data from several sources that was collected during the implementation of the Project NEURON what makes me tick…tock unit ("Novel education for understanding research on neuroscience," 2016) was made. First, an analysis of field notes written during the phase II-unit enactment revealed that certain tensions and issues arose during the instructional shift. The difficulty of identifying unit alignment with the NGSS was discussed, and an analysis of instructional days during the unit showed a substantial shift from teacher-centered learning, to student-centered learning. Next, the identification of each of the tick…tock unit's eight lessons anchoring phenomena were identified, and it was shown that each of the unit's lessons allowed students to explore different aspects of the unit's phenomenon of circadian rhythms. An analysis of the unit's science practices showed a strong inclusion of practices in the unit's lessons, although I had some difficulty identifying the science practices in some of the lessons, and I found that various science practices were used in many of the lessons. The identification of the unit's crosscutting concepts was identified, and my analysis concluded that the CCC of cause and effect was used extensively throughout the instructional unit. In the next section, some difficulty was experienced identifying the unit's disciplinary core ideas, and I concluded that the unit was a supplemental biology unit, and I assumed that it was not meant to replace traditional content which I believe accounts for this discrepancy. Finally, issues were identified relating to the extreme specificity in how the NGSS performance expectations were written allowed for only one PE match in the unit.

A qualitative analysis of data collected during critical friend's reflections and validations during Professional Learning Community (PLC) meetings revealed themes relating to model NGSS curriculum, performance expectation tensions, and tensions in curriculum alignment. Sub-themes were identified and discussed relating to the PLC member's quest for identifying qualities of a model NGSS curriculum, including the presence of the three-dimensions in the curriculum, varying science practices, performance expectations that assess activities in the unit, the use of models, and varied three-dimensional summative assessments with scoring rubrics. Data collected during the PLC discussions also brought to light tensions related to making sense of the NGSS's performance expectations. These tensions were revealed in the sub-themes of whether the PE’s are set, negotiating the purpose of the PE’s, the role of PE’s in a unit’s assessment, the narrowness and restrictiveness of the PE’s, the PE’s ability to be used flexibly, and their allowance for differentiation. The theme of curriculum alignment tensions and issues was also explored through data analysis. Discussions of the school district’s curriculum adoption and NGSS alignment brought to light sub-themes of pilot curriculum, the EQuIP rubric and curriculum alignment tensions, tensions surrounding the pilot timeline, and finally, issues related to curriculum uncertainty and differentiation of instruction.

Next, in phase II, data was collected in the form of student work. Student work was analyzed from two sources for evidence of three-dimensional learning, and it was determined that the process of model creation with multiple model revisions constitutes proof of three-dimensional learning in the unit. A self-study class portrait was presented using data collected via video and audio tape recordings to present a picture of classroom activity during the Project NEURON unit as compared to the ecology II unit. The class portrait revealed a much different learning environment compared to the traditional unit, where students were involved in loud and boisterous conversations, but they still worked effectively in groups to explore the unit’s storyline.

Further data analysis in phase II resulted in the creation of a unit concept map and tag clouds. The unit concept map presented the recursive nature of a student-centered classroom, which contrasted with the teacher-centered unidirectional nature of the concept map in the ecology II unit. Data collected via the general reflective comments, points of tension, and issues of control in the phase II field notes provided another lens to view aspects of the instructional unit. Issues and tensions were discussed relating to instructional shifts, curricular implementation, and pedagogical concerns.

Phase II Research Questions

In phase II, I asked the research question: How does implementing a biology unit that more closely aligns to the NGSS change my instructional methods, and what issues become evident during this implementation?

Table 16

Instructional Changes Between the Ecology II Unit and the Project NEURON Unit

Instructional change	Ecology II unit	Tick…tock unit
Classroom structure	Teacher-centered	Student-centered
Teacher’s role	Content expert	Learning monitor
Content dispersion	Teacher dispersed	Student groups
Formative assessments	Individual completion	Group completion
Science practices	Confirm phenomenon	Explore phenomenon

Table 16 highlights some of the instructional changes that I experienced between the ecology II unit and the tick…tock unit. One of the most striking differences between the two units was the shift from a teacher-centered classroom where I held the role of the content expert, to a student-centered classroom where I became a learning monitor. I found that there was nearly a complete role reversal during phase II of the study in my capacity as a teacher. As a more traditional teacher, I was used to being the content expert, or the specialist through whom the knowledge flows. The shift in roles was disconcerting, as I felt I had lost power and control over my classroom and my students. The field notes reflections revealed that I was anxious, especially with regards to the biology content that I was teaching. The dispersion of content shifted from me as a teacher lecturing, to students learning the content together in cooperative groups.

Some of my initial anxiety subsided when I came to the realization that only parts of the Project NEURON unit were aligned with the content that was outlined in the DNA and cell division unit’s UBD. I also felt stress when I realized that the unit was taking much more time than I had originally anticipated. Due to these time constraints, I made the decision to shorten some of the units' lessons to meet the 20-day instructional time limit that I had allotted to both phases I and to phase II data collection. I also found that students worked together as learning communities to complete formative assessments during the tick…tock unit, in contrast to the individualized assignment completion often seen in the ecology II unit.

During phase II of the study, I found that it took considerably longer to prepare for each lesson, but once the lessons were underway, I discovered that I had most of the class time to interact with students and to monitor their progress. This contrasts with when I teach science traditionally where most of the contact that I have with students is from a position of power as I direct instruction and all aspects of our interactions. I had originally assumed that I would play more of an active role in the Project NEURON unit, but I found that assumption to be incorrect. In fact, at times if felt inadequate in my capacity as a teacher because of the prolonged years of constantly being in the classroom spotlight, and now students were busy engaging with practices in groups, and I felt left out. On many occasions, students were so highly engaged with what they were learning that they ignored me as I observed them. I felt like I was intruding as I approached their groups and I tried not to interrupt their conversations. In my field notes, I commented that students were so loud while they were engaged in group conversations that it was causing me some stress, but I decided to let it go. It seemed that whenever I approached groups to monitor their progress, the group members were on task even though it did not seem so from a distance. Eventually, the increase in noise level during activities became more acceptable to me, and I became more used to it.

There is a common idea in literature that a teacher's identity can change over time with the influence of various factors that can be both external and internal (Beauchamp & Thomas, 2009). I believe that my identity as a teacher will change as I renegotiate my role in a student-centered learning environment. This renegotiation of my teaching role will allow me to assess what I valued about my role in a teacher-centered classroom and to reconsider my professional identity in a student-centered setting. This process will take time, and I am still unsure if I will be satisfied with the outcome.

The project neuron unit provided many formative assessment opportunities for students, and I spent a considerable amount of time grading the assignments. However, due to the absence of summative assessments in the unit, I decided to transform the sleep study into a summative assignment which the students had two and a half weeks to complete and turn in for the summative grade. The sleep study assignment and associated rubric are found in Appendix O.

The second research question in phase II asks: How closely does the Project NEURON unit align to the NGSS and three-dimensional learning? The field notes data that was collected during phase II revealed that the Project NEURON unit was strong in its use of both science practices, and crosscutting concepts. Additionally, the presence of a unit storyline and phenomenon allowed for the investigation of circadian rhythms using varied instructional approaches. During my initial evaluation of the “tick…tock” unit using the EQuIP rubric, I found that the unit failed to meet the rubrics’ three-dimensional learning standards due to a misalignment with the three-dimensions of the NGSS. The evaluation made it clear that the main issue with the units’ alignment with the NGSS lies in the units’ content, or disciplinary core ideas (DCI’s). Throughout much of the instructional unit, I could identify the life science DCI: LS2.C, ecosystem dynamics, functioning, and resilience. However, at times I felt that connecting this DCI with the unit’s phenomenon was difficult because circadian rhythms are not specifically mentioned content in the NGSS.

Lessons in the unit which established the relationship between circadian rhythms, DNA, mutations, and protein synthesis, were easily identified with DCI: LS3.A, inheritance of traits, and DCI: LS3.B, variation of traits. DCI: LS1.A, structure and function, was also identified in some of the lessons, especially lessons having to do with molecular biology. I contend that the Project NEURON unit, having been written prior to the release of the NGSS, was never originally intended to align with the three-dimensions of the NGSS. However, I believe that the unit can be used as a springboard for teachers who are transitioning to a student-centered curriculum and need to be tried and tested instructional units such as those that are available through Project NEURON.

Phase III - After Enactment

In phase III of this self-study, a cyclical approach is taken to analyze the data collected during phase II of the study during the promulgation of the Project NEURON unit, and to combine that data analysis with my experience and understanding of the NGSS to address the phase III research questions. First, I will give suggestions for modifying the Project NEURON unit to better align with the NGSS. My intent is not to redesign the Project NEURON unit because I believe that would be impossible due to the scope of the unit's biology content. Instead, I intend to make suggestions to improve the unit from the data that was collected during phase I and phase II of the study. In the second part of phase III, I will discuss some of the criticisms and recommendations that I have concerning the implementation of the NGSS in secondary biology classrooms. Considering my suggestions and recommendations, I hope to provide insight into my experiences during this study that could benefit other science teachers experiencing the transition to the NGSS. Finally, I will make a supposition, based on data collected during this study, as to my whether self-study can be used to guide teachers while navigating and implementing the three-dimensions of the NGSS in their classrooms if professional development is not available to them.

Phase III Research Questions

The research questions for Phase III are:

1. After data analysis, how can the Project NEURON unit be further modified to become more closely aligned with the NGSS and three-dimensional learning?
2. What recommendations and criticisms of the NGSS instructional unit implementation process can be made to help other traditional teachers make the transition using professional development and self-study?
3. Can a self-study be used to guide my transition from teaching traditionally, to teaching a unit that aligns with the three dimensions of the NGSS?

Project Neuron Post-Analysis

In this section, I will consider the phase III research question: After data analysis, how can the Project NEURON unit be further modified to become more closely aligned with the NGSS and three-dimensional learning?

The tension that I experienced when I considered varying my instructional approach as a teacher with instructional methods in the traditional spectrum, to using teaching methods that I was unsure of but I assumed were better aligned to the NGSS, remained as I began phase II. This was not an easy instructional transition because I had questions about the project neuron unit NGSS alignment from the beginning. Table 17 articulates some of the concerns that I had with the Project NEURON NGSS unit alignment and my proposed solution for tension-resolution.

Table 17

Initial Project NEURON (PN) Unit Tensions with the NGSS, and Alignment Resolutions

Initial PN Unit Tensions	PN Tension Resolution
• Lack of unit pretest and posttest	• Creation of unit pretest and posttest
• Lack of summative assessments	• Modification of sleep study Tick…tock unit summative exam
• Disciplinary Core Ideas (content) misalignment	• Unresolved
• Performance Expectation misalignment	• Unresolved

The central issues that faced me in recommending a change in this unit focused on creating a pretest and posttest, the lack of unit summative assessments, disciplinary core idea and performance expectation issues in the unit.

Tick…Tock Unit Pretest and Posttest

The what makes me tick…tock unit curriculum did not come with a unit pretest or posttest. I believe that the addition of a pretest and posttest would help the unit conform to the recent state requirement in the that teachers evaluate learning using Student Learning Objectives (SLO). According to the Illinois State Board of Education Student Learning Objective Guidebook, “A Student Learning Objective (SLO) is a detailed process used to organize evidence of student growth over a specified period of time” (Zaleski, 2015, p. 4). The SLO guidebook also states that SLO’s provide educators with a process to help them “organize evidence of student growth,” and evidence of SLO implementation have become part of teacher’s performance evaluations. Due to the requirements of the state and local school district, unit pretests and posttests have become “best practice” in our school district. Teachers are required to include pretests and posttests in each unit, two of which are evaluated during a tenured teacher’s two-year evaluation cycle. A pretest and posttest were developed for the unit so that other practitioners could access them in the future to meet district and state SLO requirements. I present a disclaimer that I am not a trained curriculum developer, nor have I been trained in assessments that align to the NGSS. My attempt at assessment creation in phase III relies on my experience writing assessments as a practitioner for two decades.

The pretest and posttest were not developed or assessed during unit enactment in this study due to the uncertainty of time constraints. The tests were written after the completion of the unit for use by other educators enacting the unit in the future. The unit pretest consists of four questions, and both the pretest and posttest can be viewed in Appendix P. In the first pretest question; students are given a scenario that asks them to construct an initial model to help describe how they conceptualize the concept. Some of the ideas for the pretest and posttest questions are modifications of questions found in the Project NEURON unit ("Novel education for understanding research on neuroscience," 2016). The first question asks:

1. You've been chosen by NASA to be part of the first manned mission to Saturn. Your team will be spending one year establishing a colony on Saturn. It only takes 11 hours for Saturn to make a full rotation, as compared to Earth's 24-hour day. Draw a model of what you think your sleep/wake cycles will be like during your yearlong mission to Saturn. Be sure to describe your model in detail using complete sentences.

This question was written to replace the initial model creation question in lesson one. On day one in the tick…tock unit, students are asked to create their original models of how they perceive sleep/wake cycles. I decided that it would be expedient to have students develop their initial sleep/wake cycle models in the pretest instead using the scenario of a manned mission to Saturn.

In the second pretest question, I asked students to make a prediction about how they believe temperature fluctuations would influence the astronauts' sleep-wake cycles.

2. During your mission to Saturn, you find that the planet has an average temperature of minus 288 degrees Fahrenheit. The heaters in the base struggle to warm the interior of the base, and the crew is constantly trying to keep warm. Predict how you think these cold temperatures will affect your sleep/wake cycle.

Students will later modify their hypothesis about the effects of sleep/wake cycles and the effects that temperature has on them. In the third pretest question, I introduced the concept of DNA mutations caused by radiation to allow students to demonstrate their prior knowledge of DNA structure and mutation.

3. You have been exposed to a burst of gamma radiation during your mission to Saturn, and your DNA has been damaged. Draw a model of your DNA which shows the damage that has been done to your DNA. Hypothesize how you think that your damaged DNA will affect your sleep/wake cycle.

In the fourth pretest question, I extend the scenario to include the absence of light in the sleep-wake cycle, so that students can hypothesize the effect that it will have on the sleep-wake cycle.

4. A massive storm has blocked out all the sunlight on Saturn for two months during your mission. To conserve power, you are only allowed one hour of artificial light each day. The rest of the time you spend in complete darkness. Predict how you think this reduction in light will impact your sleep/wake cycle.

All four of these pretest questions pertain to concepts students will learn during the unit, and I believe that assessing their preconceptions in the pretest will provide the teacher with a valuable gauge to assess their learning during the unit.

The posttest is like the pretest as it asks students to demonstrate their conceptions of the sleep/wake cycle in the same question format, only using a different scenario that was presented in the pretest. In the posttest, the scenario has changed to one of an underwater expedition to the deepest part of the ocean. The process of changing posttest questions to assess the same content while using an alternate scenario is called “mirroring.” The pretest and posttest assessment results can be used as a teacher’s SLO requirement to predict and measure student growth.

Sleep Study Summative Assessment

The grading policy for our school district requires that each instructional unit contains a minimum of two summative assessments. To comply with that requirement, the first summative assessment that I used in the what makes me tick-tock? unit was the student sleep study (Appendix O), which was modified from the sleep study found in lesson one ("Novel education for understanding research on neuroscience," 2016, p. 10). Rather than grading the sleep study as a formative assessment, the sleep study was converted to a summative investigation where students collect detailed data about their sleep/wake cycles, and the sleep cycles of one of their family members, for six days. Students collected data on Mondays, Thursdays, and Saturdays over a two-week period. They were asked to collect the following information about their sleep/wake cycles: their wake time, bedtime, total hours of sleep, the number of wake hours, quality of sleep, the number of caffeinated drinks, and any other factors that they felt impacted their sleep/wake cycles. At the end of the two-week data collection cycle, students were asked to type their reports, and to create two graphs with the following requirements: graphs were to be neat, each day should be displayed as a separate color, and a key would be included that identified each data collection day by color.

Students could present their data in any way they saw fit, and a rubric was provided with the grading guidelines. I was amazed at the range of data presentation techniques created by students. An example of a high-quality student report is presented in Appendix Q. The student's work shows the detailed data that she collected during the study using categories such as wake time, awake hours, details about what time she went to bed, total sleep, quality of sleep, the number of caffeinated drinks, and other factors. Both she and her mother's sleep patterns were neatly graphed. Students understood that the sleep study data they collected during their investigation would be used as evidence in a Claim, Evidence, Reasoning (CER) question on the unit summative exam.

The Tick…Tock Unit Summative Exam

The second summative assessment used in this unit was the unit summative exam (Appendix M). The exam was written in a question format that our biology PLC has agreed serves the needs of our students. In part one of the exam, students are asked foundational questions about circadian rhythms using a multiple-choice and true-false format. While the biology PLC understands that multiple-choice and true-false format is not necessarily the type of assessment questions that are envisioned by the writers of the NGSS, we believe that some of our students benefit from scaffolded question types to assess them on their foundational knowledge of the units' content.

In part three of the summative exam, students are asked to demonstrate their ability to design an experiment using their understanding of circadian rhythms. Students choose their own circadian rhythm related problem in the experiment, then they are asked to develop a hypothesis, and describe whether the data they would collect during the experiment would be quantitative or qualitative by providing a description of how they would collect the data. Next, students are asked to identify the control group, the experimental group, the dependent variable, the independent variable, and are asked to draw or describe in detail the experimental design using relevant biological terminology related to circadian rhythms.

In part four of the summative unit exam, students' knowledge of the structure of DNA and mutations are assessed. Students are asked to use their knowledge about the structure of DNA to neatly and accurately draw and label a DNA molecule that includes all the components that they learned in the unit, then they are asked to use their model to help them describe what mutation is, and to use their drawing to illustrate the "per" mutation that was explored in lesson, and finally to discuss the effects of the mutation on circadian rhythms.

In part four of the exam, students use the data that they collected during the summative sleep study that they conducted earlier to answer a Claim, Evidence, Reasoning (CER) question. The question, which is adapted from the what makes me tick…tock? unit, lesson 8 asks them to engage in argument from evidence to make a claim as to what time they think the school day should start ("Novel education for understanding research on neuroscience," 2016, p. 1). The question asks: Using the data that you collected during your sleep study and any other evidence that you have learned the what makes me tick-tock unit defend the reasoning for your claim. In this manner, students are asked to apply the data that they collected earlier in the unit during the sleep study to defend their claim as to when the school day should start.

Project NEURON unit reflections. It was understood from the beginning of the study that the Project NEURON unit was not designed specifically for the NGSS, but drew on earlier education reforms (American Association for the Advancement of Science, 1993; National

Research Council, 1996) for the unit's standards and benchmarks. However, I did notice that the unit contained identifiable science practices and crosscutting concepts that are found in the *Framework* (2012) and in the *NGSS* (NGSS Lead States, 2013). The most difficult part of the implementation and analysis process was the mismatch of the disciplinary core ideas to the biology content in the instructional unit that I had selected for the unit to replace. It took me some time to realize that the project neuron unit that I chose to enact was designed to investigate both genetics and neuroscience content and that it was not designed specifically with content for a secondary introductory biology survey course. It is for these reasons that I do not believe that this unit can be transformed into an NGSS unit without a complete rewrite which would start with the selection of NGSS performance expectations, and then work backwards to assure that the three-dimensions found in the performance expectations are sufficiently explored throughout the unit. However, I do not foresee this rewrite occurring, at least to meet the disciplinary core ideas of a secondary life science course.

Early during the Project NEURON unit enactment, I realized that my students were not going to be taught the content material that they might later need to be successful in advanced placement biology, or introductory college biology due to the unit being taught in place of the DNA and cell division unit at the start of the second semester. Eventually, I came to terms with this tension, and I decided after several weeks into the unit to include the content my students would miss later in the semester. Yet, as the unit progressed, I began to experience for the first time how a unit storyline could be used to explore different aspects of the phenomenon of circadian rhythms, and this process became intriguing to me. The shift in my role from overseeing nearly every aspect of the instructional time, from the dissemination of knowledge, to the structure and organization of my presentations, was noted, and eventually gave way to a realization that I would need to relinquish my role as a micromanager of instructional time that I had assumed was best for students.

I originally assumed that shifting roles to that of an NGSS teacher would be nearly instantaneous. However, I now realize that the process of role shifting is going to be a longitudinal process that will take some time, and this process is still not complete. To see students actively engaged in meaningful lessons which were designed with integrated science practices and crosscutting concepts was a novel experience for me. While I found that disciplinary core ideas were difficult to locate within the unit, the experience of enacting the unit was eye opening. I allowed my students to experience the curriculum that was designed by the Project NEURON developers. I also noticed that students who were normally silent during traditional lectures were now actively engaged in discourse with their peers and had found a voice in the classroom. The contrast from a traditional class period was striking, as students were now actively conversing about issues related to circadian rhythms instead of being passive participants.

NGSS Recommendations and Criticisms

After using self-study to examine my practice, in this section, I will answer the research question: What recommendations and criticisms of the NGSS instructional unit implementation process can be made to help other traditional teachers make the transition using professional development and self-study?

Considering my suggestions and recommendations, I hope to provide insight into my experiences during this study that will be helpful to other science teachers who are experiencing the transition to the NGSS. Teachers can benefit from the findings of this study, and they can use insights into the issues and tensions that became apparent to my critical friends and myself to

Help guide their transitions. The recommendations and criticisms I have for implementing the NGSS are listed in Table 18.

Table 18

Recommendations and Criticisms of NGSS Implementation

NGSS Implementation Recommendations and Criticisms
• Investigate the history of science education reforms • Research current "best practices" in science teaching • Have a desire to change your practice to help students learn science • Research the pedagogical changes required by the NGSS • Develop an understanding of three-dimensional learning • Understand content shifts in the NGSS • Have discussions with other science teachers about implementing the NGSS • Research curricula that were designed around the NGSS • If professional development is not available, conduct a self-study • Be an advocate for change

Early in my journey to understand the NGSS, I investigated the history of science education reforms in the United States. The findings of that investigation can be read in chapter two. I believe that practitioners who want to truly understand the NGSS should make similar efforts to research historically why the NGSS was written, and why a new science education reform was needed. So often, practitioners are asked to adhere to the latest trends in the teaching without understanding the evolution of the reform they are asked to undertake. On the NGSS FAQs page found at www.nextgenscience.org/faqs, a short description provides a basic answer to the questions: Why new science standards? Why now? One of the criticisms that I have about this description is that a much more detailed explanation should be provided as to why it is crucial that the NGSS be adopted. The rationale given by NGSS says: "States have previously used the National Science Education Standards from the National Research Council (NRC) and Benchmarks for Science Literacy from the American Association for the Advancement of Science (AAAS) to guide the development of their current state science standards"

(2013, para 1). In other words, the previous standards were old and out of date. In the same paragraph of the FAQs section, it also states that in the 15 years that those standards were developed, "major advances have since taken place in the world of science and in our understanding of how students learn science effectively." What should interest educators are the advances alluded to in this quotation. I contend that there should be a detailed description given on the NGSS website that builds a better case as to how science education reforms evolved, and what the specific forces are that drive the reforms. In this way, practitioners could understand the history, philosophy, and research behind the call for change.

On a similar note, I believe that those who intend on using the NGSS in their classrooms should research current "best practices" in science teaching, or that these best practices be explicitly stated by the developers of the NGSS. I contend that in doing so, a more convincing case can be made for transforming science classrooms from teacher-centered to student-centered learning environments. The vagueness of the statement on the NGSS FAQs website page that describes the "major advances … in how students learn science effectively" (NGSS Lead States, 2013, para 1), should be expounded on by providing a link to scholarly articles describing those practices, and an extended discussion about the benefits of the reform. Making literature available on which the reform was based would give credibility to the shift that teachers are expected to make both conceptually and pedagogically. There is, however, a "for teachers" page on nextgenscience.org that provides links to resources that can be helpful to classroom educators. While some foundational information can be found in the links on the website, a dedicated page that explains the NGSS best practices would add transparency to the argument for implementation. By gaining a researched based understanding of the "best practices" that would foster a student-centered learning environment, practitioners would have further reason to change their practice to help students better learn science. Teachers must have a true desire to change their practice for this reform to succeed, and this could be facilitated by researching the pedagogical changes required by the NGSS. Such a dramatic change can be daunting to teachers who are established in their practice, so providing real-life examples of classrooms modeling this change may help motivate teachers to elicit this change. One example of presenting real-life NGSS learning environments was found during the biology PLC's preview of the STEMscopes curriculum (Accelerate Learning, 2016). In each instructional lesson, a lesson preview video is provided which models what the enactment of the lesson looks like in a classroom.

In this study, the EQuIP rubric evaluations that I made for the different lessons provided a pivotal point in my understanding of three-dimensional learning. While evaluating units using the EQuIP rubric I finally understood the importance of having a unit storyline and phenomenon. I recommend that teachers who are transitioning to the NGSS make a regular practice of evaluating both existing and prospective lessons and curricula using the EQuIP rubric. In this way, by gaining experience using the EQuIP rubric, the requirements for an aligned NGSS unit will become more familiar, and the process can help transform their understanding of three-dimensional learning.

Another criticism of the NGSS is a lack of explanation for the content shifts that are made in the life science disciplinary core ideas (DCI's), and the life science performance expectations (PE's). Understanding these content shifts could relieve some of the tensions felt by teachers who are being asked to change the content that they have been teaching. I believe that through understanding the reasoning behind the content shifts that were made in the life sciences DCI's and PE's, it could help validate the shifts. Likewise, an explanation for the attachment of specific science practices to the life science performance expectations would help alleviate some of the tensions that were identified by PLC members earlier in this study.

A strong emphasis should be placed on the establishment of critical friends during the departmental implementation of the NGSS. Discussions with other science teachers about the intricacies of establishing a three-dimensional learning environment can give much-needed support to those who are uncertain of the pedagogical and philosophical underpinnings of the NGSS. With the help of colleagues, model NGSS curricula can be researched, and implementation issues can be identified and ironed out. In many school districts, professional development may be at the district, and not the local level, leaving many science teachers out of the discussion. In these cases, such as occurred in my situation, conducting practitioner research via action research or self-study research can allow teachers to change their practice when district professional development is unavailable. Finally, educators that successfully change their practices should be advocates for change by offering to help other teachers in their transition to a student-centered practice.

Self-Study Summary

In this section, I will answer the research question: Can a self-study be used to guide my transition from teaching traditionally, to teaching a unit that aligns with the three dimensions of the NGSS? I will present my position based on data collected during this study as to whether self-study can help guide teachers with a more traditional teaching philosophy to navigate and implement the three-dimensions of the NGSS in their classrooms. After enactment of the Project NEURON unit for twenty instructional days, I believe that the experience of closely reflecting on my practice during all three phases of the self-study has been crucial to both my understanding of the *NGSS* and in changing my conceptualization about the intricacies of three-dimensional learning. Table 19 shows the changes in my beliefs and understanding of the NGSS that I experienced during the self-study.

Table 19

Changes Experienced in My Understanding of the NGSS During the Self-Study

NGSS beliefs prior to implementing the self-study	NGSS beliefs after study implementing the self-study
• The NGSS is hard to negotiate and understand	• Understanding the NGSS requires dedication and a willingness to change
• Existing science curricula can be modified to align with the NGSS	• NGSS aligned science curricula should be written from the bottom up
• Unit lessons can have a phenomenon separate from the unit storyline	• Lessons within an NGSS unit should allow students to explore the unit phenomenon
• Three-dimensional learning can be identified in isolated instances	• Three-dimensional learning is a longitudinal process
• Performance expectations can be modified to align with curricula	• Performance expectations are what students should know and are three-dimensional
• I will immediately transition into an NGSS curriculum when it is available	• My transition to a curriculum that is aligned with the NGSS will be gradual
• Students are prepared for three-dimensional learning	• Students need time to transition into three-dimensional learning
• NGSS aligned curricula is not yet available	• Aligned NGSS curricula is currently available

Prior to undertaking this self-study, I was overwhelmed with the complexity and amount of information describing the NGSS on the www.nextgenscience.org website. However, after the time I spent exploring the NGSS through self-study, I found that understanding the NGSS takes dedication on the part of the practitioner to research the vast amount of resources available to them. Because of this study, I now believe that it takes a certain dedication and a willingness to change your practice to become a teacher that understands and wants to provide three-dimensional learning opportunities in their classroom with the goal of helping students learn and think like scientists.

Before this study, I assumed that the content and practices that I had used for several decades could be transformed to align with the NGSS. After spending a considerable amount of time developing two instructional units that were ultimately rejected due to their misalignment with the NGSS, I now understand that for a unit to align with the NGSS, it should be reverse engineered using the performance expectations. The performance expectations, which are three-dimensional, should be the guide for integrating science practices into the unit and are what students should know at the end of the instructional unit. By using this reverse engineering method, I could have eliminated the three-dimensional misalignment issues that I experienced early in this study.

During the ecology II unit, I initially thought that the POGIL assignments provided evidence of three-dimensional learning, but by the end of the self-study I came to the realization that three-dimensional learning is a longitudinal process, and it could not be identified in stand-alone instances but as the result of a process. I believe that science process actions, such as initial model development and subsequent model revisions, constitute three-dimensional learning when crosscutting concepts and disciplinary core ideas are integrated.

In the article *What is three-dimensional learning?* (2016), Joe Krajcik describes how his understanding of three-dimensional learning has changed tremendously, and he was one of the NGSS writing team leaders. Krajcik also describes how the shift to three-dimensional learning lies in the environment created in science classrooms when students use the three-dimensions to “explore, examine, and explain how and why phenomena occur and to design solutions to problems” (2016, para. 3). Experiencing this process firsthand during the Project NEURON unit was a turning point in my understanding of three-dimensional learning. Similarly, I believe that teachers undergoing NGSS professional development should be provided with a similar experience through the piloting of a well-designed instructional unit so that they can realize what three-dimensional learning looks like in a science classroom.

After conversations with my critical friends, we agreed that performance expectations, although narrow in scope, are the final evidence of what students learn during an NGSS instructional unit. In my original assumption, I argued that teachers should be able to manipulate science practices in the performance expectations to suit their assessment questions. Now at the end of this self-study, I believe that the performance expectations are the minimum that students should be able to demonstrate at the end of an instructional unit.

I initially held the assumption that if an NGSS aligned curriculum was available to me, that I would immediately change my practice to align with the NGSS. At the end of this study, I now believe that this science education reform will require a trial and error period so that I can gain fluency in the shift that the NGSS instructional methods require. I imagine that it will take several years of integrating NGSS lessons and units before I become a fluent NGSS teacher. It makes sense that the implementation process should be gradual so that teachers can pilot NGSS materials without becoming too overwhelmed with the process.

In like manner, many students have not been taught how to learn science three-dimensionally in the way that the NGSS suggests. In my experience, middle school students entering high school have been taught science with a broad range of instructional practices. The quality of instruction that they have received varies widely as well. I do not believe that all students can jump right into three-dimensional learning without some training and explanation about the three-dimensions, and the course of learning they are about to undertake. Our biology PLC has discussed beginning the school year with an introductory lesson to three-dimensional learning, where students will be taught about the eight science and engineering practices and will be able to explore examples of how each practice is designed to work. Likewise, the student would have the same experience exploring crosscutting concepts, the disciplinary core ideas, and how the NGSS performance expectations tie all three together in an assessment. The biology PLC believes that such transparency would greatly help students to conceptualize three-dimensional learning before they experience it first hand in class.

In summary, the systematic study of my practice has allowed me to make changes in how I will teach science in the future. Although the process of change is ongoing, my understanding has shifted in a measurable way as to how I view the NGSS.

Phase III Summary

In phase III of this study, I addressed the three research questions which guided the study. First, I explored how I would modify the Project NEURON unit to be more closely aligned with the NGSS and three-dimensional learning. I determined that the unit could not be further aligned to the NGSS, as there were misalignment with the NGSS life science disciplinary core ideas and performance expectations, but the unit held value as an extension unit to help teachers transition into three-dimensional teaching through its well-developed use of science practices and crosscutting concepts. I also described the unit pretest and posttest that I created for use by other teachers who need to show evidence of Student Learning Objectives (SLO) requirements. Additionally, I described the two unit summative assessment which consisted of the student sleep study, and the summative unit exam.

Next, I gave recommendations and made criticisms of the NGSS instructional unit process to help other teachers with the science education reform transition. I suggested that teachers immerse themselves in the details of the NGSS by first researching the history of science education reforms to establish a framework for the necessity of the NGSS. Other suggestions and criticisms of the NGSS implementation include; researching current best practices in science education that are integral to the NGSS, having a true desire to change your practice, familiarizing yourself with the pedagogical and content shifts in the NGSS and three-dimensional learning, opening a dialogue with other practitioners implementing the reform for support, investigating current curricula that has been designed from the bottom up around the NGSS, and being an advocate for change by conducting a self-study if professional development is not available.

Finally, in research question III, I reflected on how this self-study has been instrumental in beginning my transition to three-dimensional teaching. I highlighted beliefs, values, and assumptions that I held before starting this self-study and contrasted them to how I have changed at the end of the study. These shifts in my beliefs, values, and assumptions were at both the instructional and conceptual level and included a new understanding of three-dimensional teaching and learning and a renewed hope for an aligned NGSS curriculum in our next adoption cycle.

Chapter 4 Summary

Chapter 4 addressed the main research question: What issues arise when using self-study to guide my transition from teaching traditionally to teaching a unit that better aligns with the three-dimensions of the NGSS? In phase I of the study, I used self-study to analyze the purposeful planning of the DNA and cell division unit, and I made an evaluation of the unit's alignment with the NGSS. Next, a self-study analysis was used while I taught the traditional ecology II unit after a pre-analysis of the unit was conducted using the EQuIP rubric. A post-analysis of the ecology II unit was made using several self-study methods. The lessons' anchoring phenomenon was discussed, and analysis of the units' science practices, crosscutting concepts, disciplinary core ideas, and performance expectations was made using data collected during field note observations. A self-study class portrait of a lesson was presented from data collected using video and audio transcription during the ecology II unit. Following the class portrait, a phase I concept map and tag clouds were developed using data collected from field notes observations, and their significance to the self-study was discussed. Next, the self-study method of recounting my education-related life history was used to reflect on my identity and beliefs as an educator. An analysis of student work that was completed during the ecology II unit was made to determine if three-dimensional learning could be identified in students' responses, which was followed by a qualitative analysis of critical friend reflections as a data source to discuss themes and sub-themes related to tensions and issues that arise during implementation of the NGSS. Finally, a pre-analysis of the Project NEURON unit that was to be enacted in phase II was made to analyze the units' alignment to the NGSS.

In phase II of the study, the Project NEURON unit was adopted for twenty instructional days. Data collected through field notes during the unit enactment allowed for an analysis of the units' anchoring phenomenon, science practices, crosscutting concepts, disciplinary core ideas, and performance expectations. Next, a qualitative analysis of data collected during critical friend discussions was used to highlight themes and sub-themes that emerged concerning issues and tensions surrounding the NGSS. A self-study student work analysis was used as a data source to determine if instances of three-dimensional learning could be identified in the unit. Following the student work analysis, a self-study class portrait was presented using video and audio recordings of a Project NEURON enactment class period. Data collected from field notes was used in the next section to develop a phase II concept map and tag clouds to give an alternate method of analyzing tensions that emerged during the Project NEURON unit.

In phase III, a post-analysis of the Project NEURON unit was made to identify initial tensions uncovered during the enactment of the unit, and suggestions for their resolution were made to address research question one. Next, recommendations and criticisms concerning NGSS implementation were made to address research question two. And finally, research question three was explored through an analysis of changes in my understanding of the NGSS that occurred during the self-study.

Next, in chapter 5, a discussion about the implications of the findings in this research study will begin with a summary of the study's results in all three research phases. The curricular and instructional implications of this study in relation to their contributions to practice will be considered, followed by suggestions for further research, the limitations of the study.

CHAPTER 5 – DISCUSSION AND IMPLICATIONS

In this chapter, the findings of this self-study will be revisited to answer the overall research question which asked:

> What issues arise when using self-study to guide my transition from teaching traditionally to teaching a unit that better aligns with the three dimensions of the NGSS?

First, a summary of the findings in each of the three phases of the self-study will be made surrounding the research questions for each phase, and these findings will help in answering the study's overall research question. In the second part of this chapter, the curricular and instructional implications of the self-study will be discussed. In the final section of chapter 5, suggestions for further research relating to issues and tensions uncovered in the study will be made, and the limitations of the study will be addressed.

Summary of Findings

Research Questions Phase I

Research question one. The first research question for phase I was: What issues become evident when developing or selecting instructional units that more closely align to the three dimensions of the NGSS? Table 20 highlights issues related to research question one.

Table 20

Phase I research question one: Issues that arose when developing or selecting NGSS aligned instructional units.

Research question one emerging issues
• A misconception concerning an integrated unit storyline and phenomenon was uncovered. • The discovery that teacher identity impacts understanding the NGSS. • Teacher curricular and instructional issues and tensions surrounding the NGSS implementation emerged. • Evaluating instructional units for alignment with the NGSS revealed disconfirming alignment issues.

Selecting instructional materials that align to the NGSS has proven to be a difficult process. This sentiment is felt by some of the authors of Project 2061, the long-term science literacy initiative developed by the American Association for the Advancement of Science (AAAS). When asked about the availability of NGSS aligned material, the Project 2061's authors declared that "the answer from the standards' developers was short but not sweet: You won't find much now, and it's going to take time" (Roseman & Koppal, 2014, p. 24). The first issue that I encountered during phase I of the study was the realization that I held the misconception that a unit storyline and phenomenon was not essential for the unit's alignment with the NGSS, and that including "best practices" were sufficient for alignment. After spending a considerable amount of time writing the DNA and cell division unit, the unit was ultimately rejected for not aligning to the NGSS, and the unit's nonalignment was confirmed by the EQuIP rubric analysis. Additionally, I realized on that my identity as a traditional teacher was impacting my ability to understand the NGSS. That realization and my failed attempt at curriculum development led to my decision to conduct a self-study to change my practice.

Data collected during the qualitative analysis of critical friends' conversations during phase I revealed a wide variety of tensions and issues relating to NGSS implementation. These tensions included curriculum acquisition, curriculum uncertainty, curriculum implementation, pedagogical issues, and teacher training. I found that discussing these tensions and issues helped myself and the other members of the biology PLC to navigate and sort through the complexities of the NGSS. Additional tensions surfaced during tag cloud creation and analysis, confirming the assumption that implementing the NGSS would not be an easy transition. Most surprising was the realization that the Project NEURON unit was lacking in life science disciplinary core idea alignment with the NGSS, resulting in a score of "two" during the EQuIP rubric pre-analysis. However, it was determined that the unit contained a compelling, well-integrated unit storyline and phenomenon, strong science practices, and crosscutting concepts which are required in an instructional unit that is aligned to the NGSS. These core inclusions in the unit validated its usefulness as a transitional unit for this study. Finally, the subjective process of writing a self-study education-related life history provided an opportunity to metacognitively view my current practice, and the process helped to illicit change in my practice during the remaining phases of the self-study.

Research question two. The second research question for phase I was: How closely do the characteristics of my practice align to three-dimensional learning when teaching biology traditionally? Table 21 highlights issues related to research question two.

Table 21

Phase I research question two: NGSS alignment in the traditionally taught unit.

Traditionally taught unit three-dimensional learning alignment findings
• The traditionally taught biology unit partially aligned with the NGSS life science disciplinary core ideas. • Well-designed single assessment questions with identifiable science practices, disciplinary core ideas, and crosscutting concepts do not allow for three-dimensional learning as they do not represent a longitudinal process. • Attempting to identify the three-dimensions of the NGSS in a traditional biology unit results in questionable science practices, crosscutting concepts, and performance expectation matches. • The traditional biology unit did not contain integrated unit storylines or phenomena.

It was discovered after the EQuIP rubric evaluation, that both the DNA and cell division unit, and the traditional ecology II unit, partially aligned to the NGSS life science disciplinary core ideas. My initial assumption was that there would be no alignment, so these findings were disconfirming. The data collected during the ecology II unit showed an alignment to the NGSS disciplinary core ideas that was unexpected, and data collected using video and audio recording confirmed a teacher-centered classroom structure in the self-study class portrait. Originally, I believed that the analysis of student work during phase I revealed evidence of three-dimensional learning, however, upon reconsideration, I recounted my assertion and realized that isolated incidents such as POGIL questions were not examples of the three-dimensional learning process.

Kenneth Huff, a member of the NGSS writing team, contends that one of the common myths surrounding the implementation of the NGSS is the belief that if a curriculum covers the content, then it is aligned to the NGSS (2016). When I first noticed that certain aspects of the traditional unit that I taught aligned with the NGSS, I was hopeful that a passing EQuIP rubric score could be achieved. Initially, I had not anticipated any alignment of the traditional unit with the EQuIP rubric analysis. However, the EQuIP rubric proved to be a valuable instrument in changing my understanding of three-dimensional learning. I also discovered that without integration of disciplinary core ideas, crosscutting concepts, and science practices within individual lessons and throughout the unit, that three-dimensional learning was not possible. The science practices, crosscutting concepts, and performance expectations identified in the ecology II unit were questionable. The unexpected alignment of some aspects of the unit was attributed to the substantial inclusion of life science disciplinary core ideas, although the compelling unit storyline and phenomenon were missing.

Research Questions in Phase II

Research question one. The first research questions for phase II was: How does implementing a biology unit that aligns to the NGSS change my instructional methods, and what issues become evident during this implementation? Table 22 highlights issues related to research question one.

Table 22

Phase II research question one: Changes in instructional methods and issues that arose during the Project NEURON unit implementation.

Project NEURON changes in instructional methods	Issues that arose during the Project NEURON unit implementation
Student-centered instruction	Increased lesson preparation time, and changes observed in classroom climate
Teaching role shift to learning coordinator and monitor	Feelings of anxiety over the loss of power, and classroom control. Teacher identity was impacted.

During phase II of the self-study, it was determined that the Project NEURON unit provided an instructional platform that fostered a student-centered learning environment. Students explored the phenomenon of circadian rhythms in cooperative groups, and their learning was assessed using both formative and summative assessments. My teaching role shifted from that of a content expert in phase I to that of a learning coordinator and monitor during phase II. The shift in roles produced feelings of anxiety, and a sense of loss of power and control over my classroom. These issues resulted from tensions that I experienced over how the biology content was presented, and how biology content that was missing in the unit compared to what students were traditionally taught. Other issues that were identified during phase II centered around unit completion time, and tensions over semester biology content coverage. An increase in lesson preparation time was experienced as compared to the time usually spent preparing for more familiar content, and classroom climate changes were noted. The natural orderliness and control that was characteristic in my class during teacher-centered instruction gave way to student groups during phase II who were loud and animated, although observations showed that students remained on task even as classroom noise increased. The change in teacher identity that will need to be negotiated, and my teaching role and classroom environmental dynamics in a student-centered classroom will be an ongoing discovery process that has an uncertain outcome.

Research question two. The second research question for phase II was: How closely does the Project Neuron unit align to the NGSS and three-dimensional learning? Table 23 highlights issues related to research question two.

Table 23

Phase II research question two: Project NEURON unit three-dimensional alignment.

Three-dimensional alignment
• The disciplinary core ideas and life science performance expectations in the Project NEURON unit were difficult to align with the NGSS. • The unit contained a well-developed unit storyline and integrated phenomenon. • Science practices and crosscutting concepts were in alignment with the NGSS in the Project NEURON unit.

Phase II began with the realization that the Project NEURON unit EQuIP rubric pre-assessment showed a misalignment with the NGSS disciplinary core ideas and performance expectations due to the unit's content focus on circadian rhythms. Even though the unit earned a "two" on the EQuIP rubric pre-assessment, I understood that the unit provided the requisite model for implementing NGSS-like student-centered instruction, coupled with strong science practices and crosscutting concepts. The unit provided opportunities for three-dimensional learning through the usage of repeated cycles of model development, the planning and carrying out of investigations, and engaging in argument from evidence.

Research Questions Phase III

Research question one. The first research questions for Phase III was: After data analysis, how can the Project NEURON unit be further modified to become more closely aligned with the NGSS and three-dimensional learning? Table 24 highlights issues related to research question one.

Table 24

Phase III research question one: Project NEURON NGSS alignment.

Suggestions for better aligning the Project NEURON unit to the NGSS
• The unit cannot be further aligned to the NGSS, only improved. • The inclusion of a unit pretest and posttest will improve the unit for SLO requirements. • A unit summative exam was written to meet district assessment requirements and to improve the unit. • The student sleep study was converted to a unit summative assessment.

During phase III, suggestions were made for how the Project NEURON unit could be more closely aligned with the NGSS and three-dimensional learning. I determined that the unit could not be further aligned to the NGSS due to the issues with the NGSS life science disciplinary core ideas and performance expectations, but that the Project NEURON unit was valuable as a transitional unit to help teachers move into three-dimensional teaching through its well-developed use of science practices and crosscutting concepts. Suggestions for improving the unit included the development of a unit pretest and posttest for use by other teachers who need to show evidence of Student Learning Objectives (SLO) requirements. A description of the two unit summative assessments was given, which included the student sleep study, and the summative unit exam.

Research question two. The second research question for phase III was: What recommendations and criticisms of the NGSS instructional unit implementation process can be made to help other traditional teachers make the transition using professional development and self-study? Table 25 highlights issues related to research question two.

Table 25

Phase III research question two: NGSS implementation recommendations.

Recommendations for implementing the NGSS
• Teachers should understand the call for science education reforms either through research or professional development.

Table 25 Continued

Recommendations for implementing the NGSS
• Teachers should have a true desire to change their practice. • Understanding the pedagogical and content shifts required by the NGSS should be undertaken via self-study or professional development. • Teachers should begin a dialogue with other practitioners about the NGSS to establish a support network. • Curricula that aligns with the NGSS should be researched and examined by teachers and the curricula should be evaluated with the EQuIP rubric. • Teachers should become advocates for change by attending NGSS professional development or conducting a self-study of their practice to elicit change.

In research question two, recommendations and criticisms of the NGSS instructional unit process were made with the intent of helping other teachers experience the transition to the NGSS. Suggestions were made for teachers to first immerse themselves in the details of the NGSS by researching the history of science education reforms to establish a framework for the necessity of the NGSS, by researching current best practices in science education that are integral to the NGSS. This can be accomplished through researching the topic, or through professional development. Teachers should also have a true desire to change their practice to realize the promises of the NGSS. Other suggestions included; having teachers familiarize themselves with the pedagogical and content shifts found in the NGSS and three-dimensional learning, and opening a dialogue with other practitioners implementing the reform and establishing a support network. Teachers should also investigate current curricula that has been designed from the bottom up around the NGSS, and curricular alignment with three-dimensional learning should be assessed using the EQuIP rubric. Finally, teachers should become advocates for change by conducting a self-study if professional development is not offered by local school district.

Research question three. The third research question for phase III: Can a self-study be used to guide my transition from teaching traditionally, to teaching a unit that aligns with the three dimensions of the NGSS? Table 26 highlights issues related to research question three.

Table 26

Phase III research question three: Self-study as a mechanism for teacher change.

Instructional and conceptual changes in my views during the self-study
• Understanding the NGSS requires dedication and a willingness to change. • NGSS aligned science curricula should be written from the bottom up. • Lessons within an NGSS unit should allow students to explore the unit phenomenon. • Three-dimensional learning is a longitudinal developmental progression. • Performance expectations are what students should know and are three-dimensional. • My transition to a curriculum that is aligned with the NGSS will be a gradual progression.

In chapter four, I discussed beliefs that I held before starting this self-study and contrasted them to changes in my beliefs at the end of the study. I found that I had developed a desire to change my practice to embrace the shifts that would be required to implement the NGSS in my classroom. I also concluded that the NGSS is a complicated science education reform that takes study and dedication to understanding. Science curricula that are written from the bottom up around three-dimensional learning are much more likely to have a successful EQuIP rubric evaluation. I discovered that science lessons in NGSS units should have storylines and phenomena that integrate throughout the unit, not just within the lessons themselves. The process of learning three-dimensionally was also found to be a longitudinal, developmental progression that takes time, exposure, and practice on the part of both the teacher and students and the process should be gradual until proficiency is achieved. And finally, performance expectations can be viewed as the NGSS "standards," and are what students should know at the end of an instruction unit. The shifts in my beliefs during this study were on both the instructional and conceptual level and included a new understanding of three-dimensional teaching and learning and a renewed hope for an aligned NGSS curriculum in our next adoption cycle.

Curricular Implications

My hope is that the curricular impact of this study can help guide other secondary biology teachers in the development and selection of curricula that aligns to the NGSS. The findings of this study suggest that practitioners who do not have a thorough understanding of what the NGSS requires in terms of three-dimensional learning are ill-equipped to modify their existing lessons and units to align with the NGSS, and repurposing of existing of traditional curricula should be avoided. My original assumption that existing curricula could be amended to align with the NGSS was reversed. I now believe that an NGSS aligned curriculum should be written from the ground up using the NGSS life science disciplinary core ideas as the starting point, and the life science performance expectations as the final endpoint. In this way, instructional unit development can be focused and concentrated on the instructional shifts suggested by the NGSS without being sidetracked by a desire to include instructional material that does not align three-dimensionally. In my situation, I did realize until later in the study when I began evaluating instructional units using the EQuIP rubric that storyline and phenomenon inclusion in an instructional unit is crucial to aligning the unit the three-dimensions of the NGSS. I suggest that traditional teachers work together with their colleagues to research curricula being developed which align to the NGSS, and is written from the bottom up for the NGSS.

The curricular re-writing that would be required to align a unit such as the traditionally taught ecology II unit would be too time-consuming for teachers to undertake. Teachers would also be tempted to include and adapt some of their favorite activities that are not based on three-dimensional learning. I suggest that traditional science units such as the ecology II unit, even though they contain relevant biological content and some tried and true labs, should be scrapped and replaced by freshly developed and aligned NGSS lessons and units using NGSS best practices. It is my contention after conducting this study, that curriculum development should be left to the experts, and high-quality NGGS aligned instructional materials should be provided by the state and local school districts, and not be developed by teachers who have been trained as instructional experts, not curriculum designers. That is not to say that practitioners should not act as advisers during the development of NGSS aligned curricula, such as when teachers were asked to be involved in the writing of the NGSS. Their pragmatism and real-life experience is most certainly needed in an advisory role.

During a recent district NGSS alignment meeting, our PLC member representative Joan was introduced to a newly released, customizable STEM curriculum called “STEMscopes” (Accelerate Learning, 2016). STEMscopes NGSS claims to be designed and built from “the ground up” during the last two years to “demystify” the NGSS. In other words, the curricula they have developed have not been realigned from curricula that were designed prior to the NGSS. I found evidence of “curriculum recycling” in other curricular examples that I evaluated such as in *Biology for the NGSS* (Allan, 2014), which revealed itself to be a workbook weak in science practices and lacking in three-dimensional learning. The STEMscopes curriculum was designed and written in the proven 5E format (Bybee et al., 2006). In my initial attempt to develop an “aligned” NGSS curriculum, I used the 5E format to write the DNA & cell division unit. However, unlike my attempt at writing an NGSS aligned unit, which lacked a unifying storyline and phenomenon, the STEMscopes units have incorporated all three-dimensions of the NGSS into their units and lessons through unifying storylines and phenomena. The

STEMscopes curriculum is one of the curricular contenders to be piloted during the next school year in our science departments curriculum adoption cycle.

The findings of this study show that a curriculum such as the Project NEURON "tick...tock" unit, which was written prior to the development of the NGSS, can be used as a supplemental unit to help teachers in their transition to aligning their practice to the NGSS. The Project NEURON unit was designed with an essential requisite to NGSS alignment: It has a well-integrated phenomenon which drives the investigation of circadian rhythms.

Other Project NEURON instructional units, which are available on https://neuron.illinois.edu/, provide a free, professionally developed resource for biology teachers to supplement or replace instructional units with research based curricula. Some of these instructional units are:

- Do you see what I see? Light, sight and natural selection.
- What can I learn from worms? Regeneration, stem cells, and models.
- Why dread a bump on the head? The neuroscience of traumatic brain injury.
- What changes our minds? (Drugs) Foods, drugs, and the brain.
- Food for thought? What fuels us? Glucose, the endocrine system, and health.
- What makes honey bees work together? How genes and environment affect behavior.
- How do small things make a big difference? Microbes, ecology, and the tree of life.

Each of these instructional units incorporates unit storylines and phenomena, science practices, crosscutting concepts, and disciplinary core ideas. Project NEURON is currently working with local science teachers to write additional instructional units that are aligned to the NGSS. The NGSS aligned units will be available on the Project NEURON website once they are complete.

Instructional Implications

The transition from a traditional, teacher-centered science practice, to a student-centered approach to teaching science, was found to be a difficult endeavor. This self-study allowed for the detailed documentation of tensions and issues that arose after leaving the comfortable practice of running my classroom as an expert who oversaw all aspects of teaching and learning, and I found myself relinquishing my classroom control to student-led groups. Concerns about teachers making sense of changing instructional ideas are not new. One researcher contends that perhaps the greatest challenges that teachers face in implementing instructional reforms is making sense of the reform itself, and gaining new skills to carry out the instructional shift (Windschitl, 2002). I experienced some of these tensions when trying to make sense of the NGSS.

Running a student-centered classroom was more challenging than I originally anticipated. It took some time to grapple with the approach after years of being the center of attention in my classroom, and my understanding of a student-centered classroom is still evolving. Researchers have identified student-centered learning as an instructional approach that replaces teacher-led lectures with team-based learning, where students are held responsible for their learning, and where open-ended problems that require creative and critical thinking skills are presented (Felder & Brent, 1996). This was the learning approach created by the Project NEURON curriculum. Researchers also found benefits of student-centered learning, which include better retention of knowledge, increased motivation to learn, and a better appreciation of the subject matter being learned (1996). Yet, researchers contend that there is a "pervasive educational conservatism that works against efforts to teach for understanding" (Windschitl, 2002, p. 131). I found my conservatism in conflict during the Project NEURON instruction. Deciding how to negotiate my learning progression as I transition to full NGSS implementation over the next several years will continue to be a source of tension in my practice. Another tension revealed in this study concerned the shift in instructional time.

In this self-study, the dynamics of instructional time changed dramatically. During the traditional ecology II unit, students sat at their desks quietly during lecture. I was in full control of the class and all of the activities. Students raised their hands when I asked them questions, and I chose who answered. I could ensure that students received all the content that the district approved ecology Understanding by Design (UbD) required that I teach. This mindset of the teacher as the purveyor of knowledge is another challenge I face in my learning progression, and one other teachers will face in their transitions to a student-centered classroom. In the teacher-centered learning environment, students worked independently, and sometimes within groups. While teacher-centered learning provided for a very orderly classroom, there were some distinct disadvantages to this instructional method. Students sometimes looked bored during instructional time, and I questioned whether they were on task. When students did work together in groups during labs, and on assignments, they were not functioning as problem-solving teams in a teacher-centered setting. Instead, students were just providing each other answers to questions asked in assignments. I also noticed that some students preferred to work independently and that they appeared not to enjoy being part of a group. The students who answered questions during lectures were usually the same students, and they were mostly outspoken males. The other, shyer students, sat quietly and did not offer to join in the discussion.

During the Project NEURON unit, the instructional dynamics were quite different. Students worked predominantly in groups except during lesson transitions when I would highlight aspects of the next lesson. The student groups seemed much more interested in what they were learning, and they were more in charge of the learning pace. I noticed that students mostly asked questions to other group members, and only resorted to asking questions of me to clear up procedural issues. Students used collaborative communication skills when in their groups, and they were forced to negotiate interactions with their peers. I found that this new classroom dynamic resonated with my idea of what three-dimensional learning should look like, and my goal will be to recreate this environment in my remaining years as a practitioner.

One negative aspect that I noticed during the student-centered sessions included a much noisier classroom. The volume level in the classroom was disconcerting, and I experienced tension at not being in control of the class. Some of the groups also appeared to be off the task at times, yet they always somehow completed the lesson assignments. My teaching role had changed, and I felt more like a facilitator than an instructor, which gave me a sense of uselessness at times. I also tried not to answer student questions that they could figure out within their groups, and this led to a few instances where students seemed agitated that I would not just give them the answers. I also had the sense that some of the students were not getting the relevant facts out of the lessons that their groups were exploring, and this, combined with a feeling of losing my long-established identity left me feeling disconcerted.

After piloting the Project NEURON unit, the discomforts that I felt during implementation diminished in some respects, and remained the same in other ways. As with any new experience, the initial implementation of a student-centered instructional unit was novel and difficult to negotiate, but with time and expertise I am confident that the discomfort I felt will diminish. Concerns about whether my instructional approach is effective with regards to planning, implementation, and assessment will always be a concern to me as it should be for any teacher who cares for their students. The process of changing ones' practice after several decades of teaching is bound to be an uncomfortable experience, especially in the teacher's shift in roles.

I believe that it is imperative that traditional teachers understand the noticeable shift in roles that they will experience in a student-centered classroom. Making other science teachers aware of this role shift is one of the findings in this study of importance. For a teacher to assume such a different classroom role after many years establishing their professional identity can be disconcerting. I suggest that the instructional transition to the NGSS be gradual and then increase with proficiency. Teachers should start by selecting and teaching lessons that align with the NGSS that are rich in integrating the three dimensions. After teachers adapt to the shift in instructional roles and students become adjusted to the change in pedagogy, they can then gradually include more NGSS aligned lessons, and then units into their repertoire. This will benefit both the teacher and their students.

Understanding the instructional implications of the NGSS are of the utmost importance to the science education reform's success. Some of these instructional implications include; the challenges and benefits inherent in shifting from a teacher-centered to a student-centered learning environment, the dynamics of changes in instructional time, changes in classroom climate, and issues and tensions revolving around the teacher's instructional role. In the next section, suggestions for further research will be made.

Suggestions for Further Research

This study takes a cyclical approach to changing a teacher's practice without the use of professional development. There are, however, several research-based professional development efforts underway in the United States designed to help guide teachers transition to the Next

Generation Science Standards (Boesdorfer & Staude, 2016; McConnell, Parker, & Eberhardt, 2013; Reiser, 2013). I believe that a research study that survey's the NGSS professional development efforts in the NGSS member states at the district level could be a valuable repository for teachers, local districts, and state agencies to help them identify the best models for NGSS professional development.

Many of the tensions that were discussed during our biology PLC meetings revolved around the local district's restructuring of science course content to allow for the "all students, all standards" call of the NGSS. Many school districts require three years of science for graduation, while others require two. Our PLC members believe that the two-year model of high school NGSS adoption does not provide adequate time to cover all the NGSS standards, and we face a depth versus breadth dilemma. What is being proposed is a two-year science requirement where lower achieving students take biology, chemistry, physics, earth, and space science in a condensed course sequence.

The proposed course sequence model would intersperse the earth and space standards within the life science and physical science standards in the first two years for lower achieving students who only want to take two years of science. For "college bound," tracked students, the standards would be split by semester in a three-year sequence. While this model would allow higher tracked students to take advantage of advanced placement science courses, it effectively reduces content depth in the first two years of high school. The biology PLC members contend that this plan does not account for the additional time that a course that uses three-dimensional learning requires for students to learn effectively. The authors of the Framework discuss the depth versus breadth issues when they declare that the Framework "focuses on a limited number of core ideas in science and engineering both within and across the disciplines. The committee made this choice in order to avoid shallow coverage of a large number of topics and to allow more time for teachers and students to explore each idea in greater depth" (National Research Council (U.S.). Committee on a Conceptual Framework for New K-12 Science Education Standards., 2012, p. 11). Yet, with the inclusion of earth and space sciences standards into the life sciences NGSS curriculum in a two-year plan, it will be difficult to cover all of the standards in the space of one school year, negating the content restructuring benefits proposed in the Framework. Covering all science standards in two school years would result in a tough curricular dilemma for science teachers. We argued that a three-year science requirement would better serve our students. I believe that a research study that examines the most effective, research-based science course sequences to address these concerns should be undertaken before school districts make curricular decisions that could impact the potential success of adopting the NGSS.

Another area where there is a lack of research with regards to NGSS implementation lies with the need to conduct a longitudinal study of teachers' adherence to three-dimensional learning after implementing the NGSS. Researchers should reach out to local secondary science departments and establish relationships that can be used to provide support and monitor teacher progress and adherence to three-dimensional learning. Without collecting data on three-dimensional learning implementation at the local level, it will be impossible to gauge the success or failure of the reform.

Research should also be conducted to study teacher use of performance expectations in NGSS assessment tasks. The NGSS performance expectations are designed to be the end points of NGSS instruction. Conducting a study to research the use of performance expectations could help alleviate the tensions that teachers experience designing three-dimensional assessment, and could provide a repository for NGSS aligned assessment. Although there are some new curricular resources such as those found on www.nextgenscienceassessment.org, many of the assessment tasks are "under construction," and are designed towards middle school standards.

Finally, one of the unexpected effects of student-centered learning in this study was how it impacted my professional identity. Feelings of uselessness, boredom, and loss of classroom control were just some of the issues that I experienced during the enactment of a student-centered learning unit. Further research should be conducted to gauge the psychological impact on teachers on the traditional spectrum when they shift to a student-centered learning environment, and the best way to negotiate these issues and tensions.

Changes in Traditional and NGSS Practices and Assumptions

Earlier in this study, assumptions about traditional and NGSS teaching instructional practices were highlighted. Identifying changes in these assumptions that occurred during the enactment of the Project NEURON unit will help frame my stance after enactment of the self-study, and my experience will help provide a basis for suggesting NGSS teacher professional development.

My assumption that science content in traditional instruction and the NGSS come from different sources has changed. I now believe that both traditional and NGSS content is determined by sources external to the teacher, whereas earlier I believed that traditional content was less influenced by external sources. Upon reflection, the secondary biological content that I have been led to believe that students "need" to be taught traditionally has also been written by "experts" in the field who are most likely college professors. I realize that I have been conditioned to believe that certain biology content is essential as a result of my undergraduate science education training. The suggested content changes in the NGSS come from higher education as well. According to the Framework, "there is a new and growing body of research on learning and teaching in science that can inform a revision of the standards and revitalize science education" (2012, p. ix). I now understand that the content that I have been conditioned to believe is what students should know is being replaced by a current, research-based biological content. Thus my assumption about content has changed.

Another assumption made earlier in the study centered around measuring outcomes. Throughout my tenure as a teacher, learning objectives have been what determines outcomes, but in the NGSS performance expectations are the standards that students should know at the end of an instructional unit. I still have difficulty with how narrow and specific the NGSS life science performance expectations are. It may take some time for me to change my assumption about their specificity, especially in what I see as the random assignment of science practices to some of the performance expectations. Perhaps after piloting future NGSS lessons and units, my assumptions will change with respect to measuring outcomes.

I have discovered that one of the most contentious issues in implementing the NGSS in my practice is the change in the instructional methods between teaching science traditionally and in the NGSS. Connecting changes in teacher identity to the belief that my role will be reduced in a student-centered learning environment has helped to pinpoint the tension surrounding this issue. I realize that relinquishing what I have always considered to be one of my strengths, which is maintaining control over how content is presented and classroom control will be difficult. Yet, I know that a shift has occurred in how I view my instructional role and my identity as a teacher. By the end of the Project NEURON unit, I was still battling with these issues, and I most likely will still feel conflicted in the future.

One area where I have experienced an increase in my comfort level is when students worked in cooperative groups during the Project NEURON unit. Although I missed giving lectures, I felt a deal of satisfaction when observing students negotiate and argue with each other over the concepts they were learning during each class period during the unit. This process just felt “right” to me, and I believe that students were assuming a role that they should naturally be assuming, but one that I had been suppressing. I have assigned student group assignments regularly in the past, but students interactions were different in a three-dimensional setting. Students were wrestling with model revisions and other science practices and not just following a scripted lab or project assignment. Regardless of the feelings I experienced that my help was not needed when students were engaged with each other in groups, I realized that their interactions with each other while learning three-dimensionally was a valuable experience. Over the next several years, I will need to find my place during group interactions. In the future, rather than asking students if they have any questions, I should have questions pre-developed that allow group members to construct their understandings of the phenomenon better.

Issues and tensions surrounding the biology curriculum have been a concern during this study. In the past, I have had the freedom to modify the biology curriculum to include science topics that are particularly interesting to me, and I feel that enrich the curriculum. An example of this is the lesson and lab I teach about DNA fingerprinting, polymerase chain reaction, and gel electrophoresis during the human genetics unit. I researched and developed a simulation lab that some of the other biology teachers continue to use, but is not an “official” part of the biology curriculum. With the inclusion of the earth and space science NGSS standards which will be interspersed into the biology, chemistry, and physics curriculum, I am concerned that the ability to explore advanced topics may be prohibitive. After the first several years of teaching the

NGSS biology course, I will have a better feel for the new content and whether teacher autonomy will suffer because of an overload of content.

Related to the issue of time constraints due to the adoption of NGSS course sequences that seem to be overloaded with content, is the assumption that students will need more time to explore phenomena if three-dimensional learning is "done right." The speed of the current traditional biology course is quite fast as we are required to cover a large amount of prescribed content in a limited amount of time. Thus, the depth versus breadth controversy will continue under the NGSS. My concerns may be unfounded if the right curriculum is chosen that is well developed and thought out. If the adopted curriculum contains an integrated unit storyline, which it must to meet muster with the EQuIP rubric, and it is designed by curriculum developers who have a deep, pragmatic understanding of secondary biology, then there may be hope for successful NGSS adoption. Equally important to curricula that are aligned to the NGSS is the professional development that teachers receive prior to and during the implementation of the NGSS.

Professional Development Proposal

Reflecting on a quote by Anastasia Samaras used earlier in this study that states: "The only thing you can change in education is your own practice" (2011, p. 115), I am confident that undergoing this self-study will help improve my practice. As school districts across the United States navigate the complexities of the Next Generation Science Standards, I believe that some teachers will be left with the impression that the NGSS is a curricular reshuffling, and they will not understand the revolutionary changes in learning that result from creating a three-dimensional learning environment. Teachers are faced with a myriad of demands as practitioners, and being asked to change what they believe works during instruction can be a hard sell when such change results in increased demands on their time. When standards-based science education reforms are announced such as the NGSS, many veteran teachers will resist change as they are well entrenched in their practices. Researchers have found that "teacher's beliefs, attitudes, knowledge, self-efficacy, and teaching experience have all been shown to impact teachers' use of standards or reform-based methods in their teaching practice," and that "newer teachers were more influenced by the standards than experienced teachers" (Boesdorfer & Staude, 2016, p. 443). I have witnessed this reluctance to change firsthand amongst my colleagues and myself. Yet, I contend that change is warranted when it has the promise of teaching students to think like scientists through three-dimensional learning.

Teachers can elicit change in their practice in two different ways. First, they can decide to change their practice on their own such as the change I am experiencing because of this self-study, or they can change using professional development. In this section, I will propose two different professional development (PD) pathways that teachers may take to understand and implement the Next Generation Science Standards. PD programs that are effective share some common characteristics. Researchers have found that effective science education PD programs used collaboration and sustained coherent support to concentrate on the needs and practices of teachers in their classrooms (McConnell et al., 2013). The same research also found that knowledge of the content, as well as learning teaching strategies, were important aspects of effective PD. Other researchers have found that PD must be carefully designed when new science reform movements are launched in order to "effectively help teachers incorporate the standards into their practice for the standards to have the desired effect of transforming science education" (Boesdorfer & Staude, 2016, p. 443).

Using effective research-based professional development strategies, teachers can make a change to their practice. A research-based approach to PD is essential as "professional development (PD) for science in the U.S. does not currently reflect a coherent approach" (Reiser, 2013, p. 12). Using Reiser's research-based recommendations for professional development for the NGSS (2013), I will rely on his three recommendations of teacher "sensemaking," teacher collaboration, and using cyber-enabled environments to frame my suggestions for NGSS professional development.

Professional Development Phase I

First, teachers should be shown "rich case" examples of three-dimensional learning in classrooms that have been video recorded to make sense of the science education reform. Researchers have found that through the use of video cases they can analyze the complexity of student discourse, teacher, and student interactions, and see how the curricular materials are used to investigate the phenomena (Reiser, 2013). This recommendation is supported in the Framework which suggests that teacher's video clubs be used to "study their practices collaboratively" (2012, p. 260). I foresee beginning professional development on implementing the NGSS with multiple sessions of video case examples where teachers can compare what they observe in the video cases with what occurs in during typical instructional episodes in their own classrooms. A similar technique was used in this self-study through the process of using video recording to create a class portrait and the subsequent analysis of the classroom dynamics. Video cases that show the use of the three-dimensions and a unit storyline and phenomenon over a multiple week time frame would be the base for teachers to uncover what three-dimensional learning looks like in action. Discussions among the teachers in the professional development group could focus on changes that they observe in both the teacher and student's roles and how they can recreate those experiences in their own classrooms. The teacher could also identify the science practices, crosscutting concepts, and disciplinary core ideas in each video to help familiarize them with the layout of the NGSS.

Professional Development Phase II

In the second phase of professional development, Reiser suggests that teachers work collaboratively to apply the NGSS to their practice (2013). In this collaborative effort, teachers collaborate to apply, understand, and reflect on the science education reform, and in this way, the "sensemaking" of the reform will help them in their understanding (Putnam & Borko, 2000). I suggest that cases of teaching which are aligned to the NGSS be used as a data sources by PD group members to help them make sense of the reforms' challenges. The cases can allow teachers to develop models of their own and to construct their own explanations of what they see, both in the cases and in their own classrooms (Reiser, 2013). Teachers then begin adapting lessons to incorporate the three-dimensions of the NGSS and evaluate the lessons using the EQuIP rubric.

Professional Development Phase III

In the third phase of the NGSS professional development, teachers use "cyber-enabled environments" to incorporate technology collaboratively (Reiser, 2013). In this way, a repository of teaching materials, video cases, and other NGSS resources can be shared with PD members. Members can add curricular resources they develop or locate through research to the shared space, or even start an NGSS blog to discuss issues and tensions that arise during implementation.

Research-based professional development program like the one I just described could help science department members navigate the complexities of the NGSS before and during the implementation process. In school districts where support for NGSS professional development is not supported, the three-phase self-study methodology which was modeled in this study can elicit teacher change.

An important emphasis in the professional development program that I am suggesting is the issue of learning progressions.   In the Framework, the claim is made that it is "designed to help realize a vision of science education in which student's experiences over multiple years foster progressively deeper understanding of science" (2012, p. 217). It will take a period of years for both teachers and students to become proficient in three-dimensional teaching and learning. Both students and teachers will need to learn the intricacies of the NGSS to ensure that they progress and develop their skills as science practitioners.

Limitations of the Study

During my research, I was unable to locate other studies that investigated using self-study as a vehicle for changing secondary biology teachers' practice to better align to the NGSS. This study is significantly practitioner-centered, with the goal of changing my practice to help students learn science in a student-centered environment. Of the original twenty-seven NGSS lead states, only seventeen have begun adoption of the NGSS as their state science standards (Thakkar, 2015). In those states, many thousands of secondary science teachers are negotiating adopting the NGSS without sufficient state or district support through professional development.

All research studies have their limitations; however, this study has many. The limitations of a research study are certain characteristics of the methodology or the study design that have influenced or impacted how the research findings are interpreted (Price & Murnan, 2004). This self-study was limited to my own classroom, and how I taught a select group of freshmen accelerated biology students using two distinct instructional methods. The freshman biology professional learning community (PLC) was limited to three teachers, each with varying degrees of experience, time in service, and degrees of training in the Next Generation Science Standards. In the future, I hope to teach other practitioners how to use self-study to closely analyze their practices to shift from traditional, teacher-centered instructional methods, to more student-centered methods that align with the three-dimensions of the NGSS.

Another limitation of this study was enacting a unit that was not as closely aligned with the NGSS as I would have liked. Yet, I understood from the start that the Project NEURON unit was designed before the NGSS was published, and the inclusion of a unit storyline and phenomenon were essential to the units' consideration for enactment.

As I began to analyze my practice closely, I discovered many of my own limitations, and this self-discovery continued throughout the study and will proceed in the future. As a veteran science teacher, somewhere on the traditional spectrum, I had to consciously abandon my preconceptions and all the notions that I held about how students best learn science. At the end of the study, my practice has moved further towards the student-centered side of the spectrum and will continue to do so with time and experience working with the NGSS. Changing my mindset after two decades in the classroom is a deeply thoughtful, unsettling metacognitive process that is ongoing. The self-study process allowed me to accept and embrace new teaching methods and helped uncover many of the underlying tensions and assumptions related to developing and choosing curricula that align to the NGSS. Self-study also was instrumental in helping uncover tensions related to evaluating, teaching, and suggesting revisions for a unit the more closely aligns with the NGSS.

Discarding my biases and having an open mind towards changing my practice was a difficult process. I began this study with the assumption that I had been teaching science successfully for several decades, as many of my students had gone on to pursue careers in the sciences. So, what could possibly be wrong with my well-established pedagogy?

Trying not to exert my ideas and "teach" during student-centered learning was another difficult experience that I encountered. Trying not to give into student questions, when students are used to teachers who provide all the answers, went against the fabric of my professional identity. I felt like if I did not jump in and explain things, that some students just would not "get it." During the study, personal criticisms that I hold about the validity of three-dimensional learning as compared to more traditional methods emerged. Years of developing my persona in the classroom had to be reconsidered, and a new identity as a learning facilitator had to be self-negotiated, and that process is still ongoing.

In the future, I would be interested in interviewing other traditional teachers to compare their experiences while adopting the NGSS as compared to mine. Teacher interviews could help catalog the different experiences that traditional teachers undergo as they allow their practices to change, and then provide accounts that other teachers in our position can use to help in their transitions.

Through this self-study, my well-entrenched ideas about teaching science were closely examined. I concede that my practice will need to change for the betterment of my students, but I am still negotiating just how much and how fast the change will be. I now realize that self-study is a process that will persist as I continue in my practice.

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APPENDIX A. EQUIP RUBRIC FOR LESSONS AND UNITS: SCIENCE

by NGSS Lead States, 2016

EQuIP Rubric for Lessons & Units: Science

Version 3.0

Introduction:

The Educators Evaluating the Quality of Instructional Products (EQuIP) Rubric for science provides criteria by which to measure the alignment and overall quality of lessons and units with respect to the Next Generation Science Standards (NGSS). The purposes of the rubric and review process are to: (1) review existing lessons and units to determine what revisions are needed; (2) provide constructive criterion-based feedback and suggestions for improvement to developers; (3) identify exemplars/models for teachers' use within and across states; and (4) to inform the development of new lessons and units.

To effectively apply this rubric, an understanding of the National Research Council's *A Framework for K–12 Science Education and the Next Generation Science Standards*, including the NGSS shifts (Appendix A of the NGSS), is needed. Unlike in the EQuIP Rubrics for mathematics and ELA, there is not a category in the science rubric for shifts. Over the course of the rubric development, writers and reviewers noted that the shifts fit naturally into the other three categories. For example, the blending of the three-dimensions, or three-dimensional learning, is addressed in each of the three categories; coherence is addressed in the first two categories; connections to the Common Core State Standards is addressed in the first category; etc. Each category includes criteria by which to evaluate the integration of engineering, when included in a lesson or unit, through practices or disciplinary core ideas. Another difference between the EQuIP Rubrics from mathematics and ELA is in the name of the categories; the rubric for science refers to them simply as *categories*, whereas the math and ELA rubrics refer to the categories as dimensions. This distinction was made because the Next Generation Science Standards already uses the term *dimensions* to refer to practices, disciplinary core ideas, and crosscutting concepts.

The architecture of the NGSS is significantly different from other sets of standards. The three dimensions, crafted into performance expectations, describe what is to be assessed following instruction and therefore are the measure of proficiency. A lesson or unit may provide opportunities for students to demonstrate performance of practices connected with their understanding of core ideas and crosscutting concepts as foundational pieces. This three-dimensional learning leads toward eventual mastery of performance expectations. In this scenario, quality materials should clearly describe or show how the lesson or unit works coherently with previous and following lessons or units to help build toward eventual mastery of performance expectations. The term *element* is used in the rubric to represent the relevant, bulleted practices, disciplinary core ideas, and crosscutting concepts that are articulated in the foundation boxes of the standards and in K–12 grade-banded progressions and the NGSS Appendices. Given the understanding that lessons and units should integrate the practices, disciplinary core ideas, and crosscutting concepts in ways that make sense instructionally and not replicate the exact integration in the performance expectations, the new term *elements* is needed to describe these smaller units of the three dimensions. Although it is unlikely that a single lesson would provide adequate opportunities for a student to demonstrate proficiency on an entire performance expectation, high-quality units are more likely to provide these opportunities to demonstrate proficiency on one or more performances expectations.

There is a recognition among educators that curriculum and instruction will need to shift with the adoption of the NGSS, but it is currently difficult to find instructional materials designed for the NGSS. The power of the rubric is in the feedback and suggestions for improvement it provides curriculum developers and the productive conversations in which educators engage while evaluating materials using the quality review process. For curriculum developers, the rubric and review process provide evidence of the quality and the degree to which the lesson or unit is designed for the NGSS. Additionally, the rubric and review process generate suggestions for improvement on how materials can be further improved and better designed to match up with the vison of the *Framework* and the NGSS.

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EQuIP Rubric for Lessons & Units: Science

Lessons *and* units designed for the NGSS include clear and compelling evidence of the following:

I. NGSS 3D Design	II. NGSS Instructional Supports	III. Monitoring NGSS Student Progress
The lesson/unit is designed so students make sense of phenomena and/or design solutions to problems by engaging in student performances that integrate the three dimensions of the NGSS. A. **Explaining Phenomena/Designing Solutions**: Making sense of phenomena and/or designing solutions to a problem drive student learning. i. Student questions and prior experiences related to the phenomenon or problem motivate sense-making and/or problem solving. ii. The focus of the lesson is to support students in making sense of phenomena and/or designing solutions to problems. iii. When engineering is a learning focus, it is integrated with developing disciplinary core ideas from physical, life, and/or earth and space sciences. B. **Three Dimensions**: Builds understanding of multiple grade-appropriate elements of the science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCCs) that are deliberately selected to aid student sense-making of phenomena and/or designing of solutions. i. Provides opportunities to *develop and use* specific elements of the SEP(s). ii. Provides opportunities to *develop and use* specific elements of the DCI(s). iii. Provides opportunities to *develop and use* specific elements of the CCC(s). C. **Integrating the Three Dimensions:** Student sense-making of phenomena and/or designing of solutions requires student performances that integrate elements of the SEPs, CCCs, and DCIs.	*The lesson/unit supports three-dimensional teaching and learning for ALL students by placing the lesson in a sequence of learning for all three dimensions and providing support for teachers to engage all students.* A. **Relevance and Authenticity**: Engages students in authentic and meaningful scenarios that reflect the practice of science and engineering as experienced in the real world. i. Students experience phenomena or design problems as directly as possible (firsthand or through media representations). ii. Includes suggestions for how to connect instruction to the students' home, neighborhood, community and/or culture as appropriate. iii. Provides opportunities for students to connect their explanation of a phenomenon and/or their design solution to a problem to questions from their own experience. B. **Student Ideas:** Provides opportunities for students to express, clarify, justify, interpret, and represent their ideas and to respond to peer and teacher feedback orally and/or in written form as appropriate. C. **Building Progressions**: Identifies and builds on students' prior learning <u>in all three dimensions</u>, including providing the following support to teachers: i. Explicitly identifying prior student learning expected for all three dimensions ii. Clearly explaining how the prior learning will be built upon D. **Scientific Accuracy**: Uses scientifically accurate and grade-appropriate scientific information, phenomena, and representations to support students' three-dimensional learning. E. **Differentiated Instruction**: Provides guidance for teachers to support differentiated instruction by including: i. Appropriate reading, writing, listening, and/or speaking alternatives (e.g., translations, picture support, graphic organizers, etc.) for students who are English language learners, have special needs, or read well below the grade level. ii. Extra support (e.g., phenomena, representations, tasks) for students who are struggling to meet the targeted expectations. iii. Extensions for students with high interest or who have already met the performance expectations to develop deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts.	*The lesson/unit supports monitoring student progress in all three dimensions of the NGSS as students make sense of phenomena and/or design solutions to problems.* A. **Monitoring 3D student performances**: Elicits direct, observable evidence of three-dimensional learning; students are using practices with core ideas and crosscutting concepts to make sense of phenomena and/or to design solutions. B. **Formative:** Embeds formative assessment processes throughout that evaluate student learning to inform instruction. C. **Scoring guidance**: Includes aligned rubrics and scoring guidelines that provide guidance for interpreting student performance along the three dimensions to support teachers in (a) planning instruction and (b) providing ongoing feedback to students. D. **Unbiased tasks/items**: Assesses student proficiency using methods, vocabulary, representations, and examples that are accessible and unbiased for all students.

EQuIP Rubric for Lessons & Units: Science

<u>Units</u> designed for the NGSS will *also include* clear and compelling evidence of the following additional criteria:

I. NGSS 3D Design	II. NGSS Instructional Supports	III. Monitoring NGSS Student Progress
D. **Unit Coherence**: Lessons fit together to target a set of performance expectations. i. Each lesson builds on prior lessons by addressing questions raised in those lessons, cultivating new questions that build on what students figured out, or cultivating new questions from related phenomena, problems, and prior student experiences. ii. The lessons help students develop toward proficiency in a targeted set of performance expectations. E. **Multiple Science Domains**: *When appropriate*, links are made across the science domains of life science, physical science and Earth and space science. i. Disciplinary core ideas from different disciplines are used together to explain phenomena. ii. The usefulness of crosscutting concepts to make sense of phenomena or design solutions to problems *across science domains* is highlighted. F. **Math and ELA:** Provides grade-appropriate connection(s) to the Common Core State Standards in Mathematics and/or English Language Arts & Literacy in History/Social Studies, Science and Technical Subjects.	F. **Teacher Support for Unit Coherence:** Supports teachers in facilitating coherent student learning experiences over time by: i. Providing strategies for linking student engagement across lessons (e.g. cultivating new student questions at the end of a lesson in a way that leads to future lessons, helping students connect related problems and phenomena across lessons, etc.). ii. Providing strategies for ensuring student sense-making and/or problem-solving is linked to learning in all three dimensions. G. **Scaffolded differentiation over time**: Provides supports to help students engage in the practices as needed and gradually adjusts supports over time so that students are increasingly responsible for making sense of phenomena and/or designing solutions to problems.	E. **Coherent Assessment system:** Includes pre-, formative, summative, and self-assessment measures that assess three-dimensional learning. F. **Opportunity to learn**: Provides multiple opportunities for students to demonstrate performance of practices connected with their understanding of disciplinary core ideas and crosscutting concepts and receive feedback.

Using the EQuIP Rubric for Lessons & Units: Science

The first step in the review process is to become familiar with the rubric, the lesson or unit, and the practices, disciplinary core ideas, and crosscutting concepts targeted in the lesson or unit. The three categories in the rubric are: NGSS 3D Design, NGSS Instructional Supports, and Monitoring NGSS Student Progress. Each criterion within each category should be considered separately as part of the complete review process and are used to provide sufficient information for determination of overall quality of the lesson or unit.

For the purposes of using the rubric, **a lesson is defined as**: a set of instructional activities and assessments that may extend over several class periods or days; it is more than a single activity. A **unit is defined as**: a set of lessons that extend over a longer period of time. If you are reviewing a lesson, you will use only the first section of the rubric (page 2). If you are reviewing an instructional unit, you apply all of the criteria of the rubric (pages 2 and 3) across the unit. You'll notice that the definition of a "unit" is intentionally broad here. If you are reviewing instructional materials that cover more than a few days of instruction, use the full unit list of criteria.

Also important to the review process is feedback and suggestions for improvement to the developer of the resource. For this purpose, a set of response forms is included so that the reviewer can effectively provide criterion-based feedback and suggestions for improvement for each category. The response forms correspond to the criteria of the rubric. Evidence for each criterion must be identified and documented and criterion-based feedback and suggestions for improvement should be given to help improve the lesson or unit.

While it is possible for the rubric to be applied by an individual, the quality review process works best with a team of reviewers, as a collaborative process, with the individuals recording their thoughts and then discussing with other team members before finalizing their feedback and suggestions for improvement. Discussions should focus on understanding all reviewers' interpretations of the criteria and the evidence they have found. With professional learning support for the group, this process will provide higher quality feedback about the lessons and also calibrate responses across reviewers in a way that moves them toward agreement about quality with respect to the NGSS. Commentary needs to be constructive, with all lessons or units considered "works in progress." Reviewers must be respectful of team members and the resource contributor. Contributors should see the review process as an opportunity to gather feedback and suggestions for improvement rather than to advocate for their work. All feedback and suggestions for improvement should be criterion-based and have supporting evidence from the lesson or unit cited.

In order to apply the rubric with reliability and with fidelity to its intent, it is recommended that those applying the rubric to lessons and units be supported to attend EQuIP professional learning based on the EQuIP Facilitator's Guide. There is guidance within the rubric below and in the Facilitator's Guide, but application of the rubric is much more successful with the support of professional learning. It is difficult to develop proficiency at using the rubric without *at least* two days of high quality professional learning that engages participants in evaluating lessons and units.

Step 1 – Review Materials

The first step in the review process is to become familiar with the rubric and the lesson or unit that is being evaluated.

- Review the rubric and record the grade and title of the lesson or unit on the response form.
- Scan the lesson/unit to see what it's about; identify what practices, disciplinary core ideas, and crosscutting concepts are targeted; and determine how it is organized.
- Read key materials related to instruction, assessment, and teacher guidance.
- Read the definitions of "lesson" and "unit" near the top of this page and decide as a group whether you will be using the shorter list of criteria for a lesson, or the longer list of criteria that apply to a unit.

Step 2 – Apply Criteria in Category I: NGSS 3D Design

Evaluate the lesson or unit using the criteria in the first category, first individually and then as a team.

- Closely examine the lesson or unit through the "lens" of each criterion in the first category.
- For each criterion, record where you find it in the lesson/unit (the evidence) and why/how this evidence is an indicator the criterion is being met (the reasoning)
- As individuals, check the box for each criterion on the response form that indicates the degree to which evidence could be identified.
- Identify and record input on specific improvements that might be made to meet criteria or strengthen alignment.

- Look across the criteria of the category (A–C for a lesson and A–F for a unit), evaluate the degree to which they are met, and enter your 0–3 rating for Category I: NGSS 3D Design (see scale description below)
- As a team, discuss criteria for which clear and substantial evidence is found, as well as criterion-based suggestions for specific improvements that might be needed to meet criteria. As a team, enter your 0–3 rating for Dimension I: NGSS 3D Design.

*If the rubric is being used to approve or vet resources and the lesson or unit does not score at least a "2" in **Category I: NGSS 3D Designed**, the review should stop and feedback should be provided to the lesson developer(s) to guide revisions. If the rubric is being used locally for revising and building lessons, professional judgment should guide whether to continue reviewing the lesson. Categories II and III may be time consuming to evaluate if Category I has not been met and the feedback may not be useful if significant revisions are needed in Category I, but evaluating these criteria in a group may support deeper and more common understanding of the criteria in these categories and more complete feedback to the lesson developer (if they are not in the room) so that Categories II and III are more likely to be met with fewer cycles of revision.*

Step 3 – Apply Criteria in Categories II and III: Instructional Supports and Monitoring Student Progress

The third step is to evaluate the lesson or unit using the criteria in the second and third categories, first individually and then as a group.

- Closely examine the lesson or unit through the "lens" of each criterion in the second and third categories of the response form.
- For each criterion, record where you find it in the lesson/unit (the evidence) and why/how this evidence is an indicator the criterion is being met (the reasoning)
- Individually check the box for each criterion on the response form that indicates the degree to which evidence could be identified.
- Record any suggestions for improvement and then rate each category using the 0–3 rating scale in the forms below.

When working in a group, teams may choose to compare ratings after each category or delay conversation until each person has rated and recorded input for both Categories II and III. Complete consensus among team members is not required but discussion is a key component of the review process that moves the group to a better understanding of the criteria.

Step 4 – Apply an Overall Rating and Provide Summary Comments

- Review ratings for Categories I–III, adding/clarifying comments as needed.
- Write summary comments for your overall rating on your recording sheet.
- Total category ratings, reflect on the overall quality of the lesson or unit, and record the overall rating of E, E/I, R, or N.

If working in a group, individuals should record their overall rating prior to conversation.

Step 5 – Compare Overall Ratings and Recommend Next Steps

- Note the evidence cited to arrive at final ratings, summary comments and similarities and differences among raters. Recommend next steps for the lesson/unit and provide recommendations for improvement and/or ratings to developers/teachers.

Rating Scales

Rating for Category I: NGSS 3D Designed is non-negotiable and requires a rating of 2 or 3. If rating is 0 or 1 then a review for resource approval does not continue.

Rating Scale for Categories I, II, & III:

Rating scales are different for each category and can be found after each category in the rubric.

Descriptors for Categories I, II, & III:

3: Exemplifies NGSS Quality—meets the standard described by criteria in the category, as explained in criterion-based observations.
2: Approaching NGSS Quality—meets many criteria but will benefit from revision in others, as suggested in criterion-based observations.
1: Developing toward NGSS Quality—needs significant revision, as suggested in criterion-based observations.
0: Not representing NGSS Quality—does not address the criteria in the category.

Overall Rating for the Lesson/Unit:

E: Example of high quality NGSS design—High quality design for the NGSS across all three categories of the rubric; a lesson or unit with this rating will still need adjustments for a specific classroom, but the support is there to make this possible; exemplifies most criteria across Categories I, II, & III of the rubric. (total score ~8–9)
E/I: Example of high quality NGSS design if Improved—Adequate design for the NGSS, but would benefit from some improvement in one or more categories; most criteria have at least adequate evidence (total score ~6–7)
R: Revision needed—Partially designed for the NGSS, but needs significant revision in one or more categories (total ~3–5)
N: Not ready to review—Not designed for the NGSS; does not meet criteria (total 0–2)

EQuIP Rubric for Lessons & Units: Science (Version 3.0)

Reviewer Name or ID: ______________________________ **Grade:**__________ **Lesson/Unit Title:**____

Category I: NGSS 3D Design (lessons and units): *The lesson/unit is designed so students make sense of phenomena and/or design solutions to problems by engaging in student performances that integrate the three dimensions of the NGSS.*

Lesson *and* Unit Criteria Lessons and units designed for the NGSS include clear and compelling evidence of the following:	**Specific evidence from materials** (what happened/where did it happen) **and reviewer's reasoning** (how/why is this evidence)		**Evidence of Quality?**	**Suggestions for improvement**
A. **Explaining Phenomena/Designing Solutions**: Making sense of phenomena and/or designing solutions to a problem drive student learning. i. Student questions and prior experiences related to the phenomenon or problem motivate sense-making and/or problem solving. ii. The focus of the lesson is to support students in making sense of phenomena and/or designing solutions to problems. iii. When engineering is a learning focus, it is integrated with developing disciplinary core ideas from physical, life, and/or earth and space sciences.			☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	
B. **Three Dimensions**: Builds understanding of multiple grade-appropriate elements of the science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCCs) *that are deliberately selected to aid student sense-making of phenomena and/or designing of solutions.*	Document evidence and reasoning, and evaluate whether or not there is sufficient evidence of quality for each dimension separately	**Evidence of Quality?**	☐ None ☐ Inadequate ☐ Adequate ☐ Extensive **(All 3 dimensions must be rated at least "adequate" to mark "adequate" overall)**	
i. Provides opportunities to *develop and use* specific elements of the SEP(s).	i.	☐ None ☐ Inadequate ☐ Adequate ☐ Extensive		
ii. Provides opportunities to *develop and use* specific elements of the DCI(s).	ii.	☐ None ☐ Inadequate ☐ Adequate ☐ Extensive		
iii. Provides opportunities to *develop and use* specific elements of the CCC(s). **Evidence needs to be at the *element level* of the dimensions (see rubric introduction for a description of what is meant by "element")**	iii.	☐ None ☐ Inadequate ☐ Adequate ☐ Extensive		

C. **Integrating the Three Dimensions:** Student sense-making of phenomena and/or designing of solutions requires student performances that integrate elements of the SEPs, CCCs, and DCIs.		☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	
Rating for Category I. NGSS 3D Design—*lessons* After carefully weighing the evidence, reasoning, and suggestions for improvement, rate the degree to which there is enough evidence to support a claim that the lesson meets these criteria. ***If you are evaluating an instructional unit rather than a single lesson, continue on to evaluate criteria D-F and rate Category I overall below.***	***Lesson* Rating scale for Category I (Criteria A–C only)**: **3**: Extensive evidence to meet at least two criteria (and at least adequate evidence for the third) **2**: Adequate evidence to meet all three criteria in the category **1**: Adequate evidence to meet at least one criterion in the category, but insufficient evidence for at least one other criterion **0**: Inadequate (or no) evidence to meet any of the criteria in the category		**Select Rating** **0 1 2 3** After rating the lesson, read below for next steps

What's next if the lesson rating is less than a 2?

*If the rubric is being used to approve or vet resources and the lesson or unit does not score at least a "2" in **Category I: NGSS 3D Designed**, the review should stop and feedback should be provided to the lesson developer(s) to guide revisions. If the rubric is being used locally for revising and building lessons, professional judgment should guide whether to continue reviewing the lesson. Categories II and III may be time consuming to evaluate if Category I has not been met and the feedback may not be useful if significant revisions are needed in Category I, but evaluating these criteria in a group may support deeper and more common understanding of the criteria in these categories and more complete feedback to the lesson developer (if they are not in the room) so that Categories II and III are more likely to be met with fewer cycles of revision.*

What's next if the lesson rating is a 2 or 3?

If you are evaluating a lesson that shows sufficient evidence of quality to warrant a rating of either a 2 or a 3 for Category I, proceed to Category II: NGSS Instructional Supports

Category I: NGSS 3D Design (additional criteria *for units only*):

If you are evaluating a lesson, it is not necessary to evaluate criteria D–F. Please enter your rating for a single lesson above (after C).

Unit Criteria A unit or longer lesson designed for the NGSS will also include clear and compelling evidence of the following:	**Specific evidence from materials and reviewers' reasoning**	**Evidence of Quality?**	**Suggestions for improvement**
D. **Unit Coherence**: Lessons fit together to target a set of performance expectations. i. Each lesson builds on prior lessons by addressing questions raised in those lessons, cultivating new questions that build on what students figured out, or cultivating new questions from related phenomena, problems, and prior student experiences. ii. The lessons help students develop toward proficiency in a targeted set of performance expectations.		☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	
E. **Multiple Science Domains**: *When appropriate*, links are made across the science domains of life science, physical science and Earth and space science. i. Disciplinary core ideas from different disciplines are used together to explain phenomena. ii. The usefulness of crosscutting concepts to make sense of phenomena or design solutions to problems *across science domains* is highlighted.		☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	
F. **Math and ELA:** Provides grade-appropriate connection(s) to the Common Core State Standards in Mathematics and/or English Language Arts & Literacy in History/Social Studies, Science and Technical Subjects.		☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	
Rating for Category I. NGSS 3D Designed—*units* After carefully weighing the evidence, reasoning, and suggestions for improvement, rate the degree to which the criteria are met across the unit.	**Unit Rating Scale for Category I (Criteria A–F):** **3**: At least adequate evidence for all of the unit criteria in the category; extensive evidence for criteria A–C **2**: At least some evidence for all unit criteria in Category I (A–F); adequate evidence for criteria A–C **1**: Adequate evidence for some criteria in Category I, but inadequate/no evidence for at least one criterion A–C **0**: Inadequate (or no) evidence to meet any criteria in Category I (A–F)		**Select Rating** **0 1 2 3**

If the rubric is being used to approve or vet resources and the unit does not score at least a "2" overall in ***Category I: NGSS 3D Design****, the review should stop here and feedback should be provided to the unit developer(s) to guide revisions. If the rubric is being used locally for revising and building units, professional judgment should be used on whether or not to continue reviewing the unit. For example, a unit that is weak in one aspect of criterion A, but that the reviewers think is easy to fix, might warrant continued review to provide more complete feedback to the unit developer(s).*

Category II: NGSS Instructional Supports (lessons and units): *The lesson/unit supports three-dimensional teaching and learning for ALL students by placing the lesson in a sequence of learning for all three dimensions and providing support for teachers to engage all students.*

Lesson *and* Unit Criteria Lessons and units designed for the NGSS include clear and compelling evidence of the following:	**Specific evidence from materials and reviewers' reasoning**	**Evidence of Quality?**	**Suggestions for improvement**
A. **Relevance and Authenticity**: Engages students in authentic and meaningful scenarios that reflect the practice of science and engineering as experienced in the real world. i. Students experience phenomena or design problems as directly as possible (firsthand or through media representations). ii. Includes suggestions for how to connect instruction to the students' home, neighborhood, community and/or culture as appropriate. iii. Provides opportunities for students to connect their explanation of a phenomenon and/or their design solution to a problem to questions from their own experience.		☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	
B. **Student Ideas:** Provides opportunities for students to express, clarify, justify, interpret, and represent their ideas and respond to peer and teacher feedback orally and/or in written form as appropriate.		☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	
C. **Building Progressions**: Identifies and builds on students' prior learning in all three dimensions, including providing the following support to teachers: i. Explicitly identifying prior student learning expected for all three dimensions ii. Clearly explaining how the prior learning will be built upon.		☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	

D. **Scientific Accuracy**: Uses scientifically accurate and grade-appropriate scientific information, phenomena, and representations to support students' three-dimensional learning.		☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	
E. **Differentiated Instruction**: Provides guidance for teachers to support differentiated instruction by including: i. Appropriate reading, writing, listening, and/or speaking alternatives (e.g., translations, picture support, graphic organizers, etc.) for students who are English language learners, have special needs, or read well below the grade level. ii. Extra support (e.g., phenomena, representations, tasks) for students who are struggling to meet the targeted expectations. iii. Extensions for students with high interest or who have already met the performance expectations to develop deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts.		☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	
Rating for Category II: Instructional Supports—lessons After carefully weighing the evidence, reasoning, and suggestions for improvement, rate the degree to which the lesson met this category. ***If you are evaluating an instructional unit rather than a single lesson, continue on to evaluate criteria F–G and rate Category II overall below.***	**Lesson Rating scale for Category II (Criteria A-E only):** **3**: At least adequate evidence for all criteria in the category; extensive evidence for at least one criterion **2**: Some evidence for all criteria in the category and adequate evidence for at least four criteria, including A **1**: Adequate evidence of quality for at least two criteria in the category **0**: Adequate evidence of quality for no more than one criterion in the category		**Select Rating** **0 1 2 3**

Category II: NGSS Instructional Supports (additional criteria *for units only*)

If you are evaluating a lesson, it is not necessary to evaluate criteria F–G. Please enter your rating for a lesson above (after E).

Unit Criteria A unit or longer lesson designed for the NGSS will also include clear and compelling evidence of the following:	**Specific evidence from materials and reviewers' reasoning**	**Evidence of Quality?**	**Suggestions for improvement**
F. **Teacher Support for Unit Coherence:** Supports teachers in facilitating coherent student learning experiences over time by: i. Providing strategies for linking student engagement across lessons (e.g. cultivating new student questions at the end of a lesson in a way that leads to future lessons, helping students connect related problems and phenomena across lessons, etc.). ii. Providing strategies for ensuring student sense-making and/or problem-solving is linked to learning in all three dimensions.		☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	
G. **Scaffolded differentiation over time:** Provides supports to help students engage in the practices as needed and gradually adjusts supports over time so that students are increasingly responsible for making sense of phenomena and/or designing solutions to problems.		☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	
Rating for Category II: NGSS Instructional Supports—*units* After carefully weighing the evidence, reasoning, and suggestions for improvement, rate the degree to which the criteria are met across the unit.	***Unit* rating scale for Category II (Criteria A-G):** **3**: At least adequate evidence for all criteria in the category; extensive evidence for at least two criteria **2**: Some evidence for all criteria in the category and adequate evidence for at least five criteria, including A **1**: Adequate evidence for at least three criteria in the category **0**: Adequate evidence for no more than two criteria in the category		**Select Rating** **0 1 2 3**

Category III: Monitoring NGSS Student Progress (lessons and units) *The lesson/unit supports monitoring student progress in all three dimensions of the NGSS as students make sense of phenomena and/or design solutions to problems.*

Lesson and Unit Criteria Lessons and units designed for the NGSS include clear and compelling evidence of the following:	**Specific evidence from materials and reviewers' reasoning**	**Evidence of Quality?**	**Suggestions for improvement**
A. **Monitoring 3D student performances**: Elicits direct, observable evidence of three-dimensional learning; students are using practices with core ideas and crosscutting concepts to make sense of phenomena and/or to design solutions.		☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	
B. **Formative:** Embeds formative assessment processes throughout that evaluate student learning to inform instruction.		☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	
C. **Scoring guidance**: Includes aligned rubrics and scoring guidelines that provide guidance for interpreting student performance along the three dimensions to support teachers in (a) planning instruction and (b) providing ongoing feedback to students.		☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	
D. **Unbiased tasks/items**: Assesses student proficiency using methods, vocabulary, representations, and examples that are accessible and unbiased for all students.		☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	
Rating for Category III. Monitoring NGSS Student Progress—*lessons* After carefully weighing the evidence, reasoning, and suggestions for improvement, rate the degree to which the lesson met this category. ***If you are evaluating an instructional unit rather than a single lesson, continue on to evaluate criteria E–F and rate Category III overall below.***	***Lesson* Rating scale for Category III (Criteria A–D only):** **3**: At least adequate evidence for all criteria in the category; extensive evidence for at least one criterion **2**: Some evidence for all criteria in the category and adequate evidence for at least three criteria, including A **1**: Adequate evidence for at least two criteria in the category **0**: Adequate evidence for no more than one criterion in the category		**Select Rating** **0 1 2 3**

Category III: Monitoring NGSS Student Progress (additional criteria *for units only*)
If you are evaluating a lesson, it is not necessary to evaluate criteria E–F. Please enter your rating for a lesson above (after D).

Unit Criteria A unit or longer lesson designed for the NGSS will also include clear and compelling evidence of the following:	**Specific evidence from materials and reviewers' reasoning**	**Evidence of Quality?**	**Suggestions for improvement**
E. **Coherent Assessment system:** Includes pre-, formative, summative, and self-assessment measures that assess three-dimensional learning.		☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	
F. **Opportunity to learn**: Provides multiple opportunities for students to demonstrate performance of practices connected with their understanding of disciplinary core ideas and crosscutting concepts and receive feedback		☐ None ☐ Inadequate ☐ Adequate ☐ Extensive	
Rating for Category III: Monitoring NGSS Student Progress—*units* After carefully weighing the evidence, reasoning, and suggestions for improvement, rate the degree to which the criteria are met across the unit.	**Unit Rating scale for Category II (Criteria A–G):** **3**: At least adequate evidence for all criteria in the category; extensive evidence for at least one criterion **2**: Some evidence for all criteria in the category and adequate evidence for at least five criteria, including A **1**: Adequate evidence for at least three criteria in the category **0**: Adequate evidence for no more than two criteria in the category		**Select Rating** **0 1 2 3**

Category Ratings:

Transfer your team's ratings from each category to the following chart and add the scores together for the overall score:

Category ratings			
Category I: **NGSS 3D Design**	**Category II:** **NGSS Instructional Supports**	**Category III:** **Monitoring NGSS Student Progress**	**Total Score**
0 1 2 3	0 1 2 3	0 1 2 3	

Overall ratings: The score total is an *approximate* guide for the rating. Reviewers should use the evidence of quality across categories to guide the final rating. In other words, the rating could differ from the total score recommendations if the reviewer has evidence to support this variation.	**E: Example of high quality NGSS design**—High quality design for the NGSS across all three categories of the rubric; a lesson or unit with this rating will still need adjustments for a specific classroom, but the support is there to make this possible; exemplifies most criteria across Categories I, II, & III of the rubric. (total score ~8–9) **E/I: Example of high quality NGSS design if Improved—**Adequate design for the NGSS, but would benefit from some improvement in one or more categories; most criteria have at least adequate evidence (total score ~6–7) **R: Revision needed—**Partially designed for the NGSS, but needs significant revision in one or more categories (total ~3–5) **N: Not ready to review—**Not designed for the NGSS; does not meet criteria (total 0–2)	**Select the overall rating below:** **E E/I R N**

Overall Summary Comments:

APPENDIX B. SCIENCE LESSON EVALUATION: FIELD NOTES

Adapted from the EQuIP Rubric for Lessons & Units: Science, by NGSS Lead States, 2016

In the Public Domain.

Science Lesson Evaluation: Field Notes

Adapted from the EQuIP Rubric for Lessons & Units: Science (NGSS Lead States, 2013)

* Required

1. Today's Date

   Example: December 15, 2012

2. Evaluation Time

   Example: 8:30 AM

1. NGSS Alignment Criteria Checklist - Evidence of three-dimensional learning

NGSS Alignment

3. Lesson's Anchoring Phenomena/Problem

4. NGSS Dimension One: Science Practices (select all that apply)

   Check all that apply.

- [ ] Asking questions
- [ ] Developing and using models
- [ ] Planning and carrying out investigations
- [ ] Analyzing and interpreting data
- [ ] Using mathematics and computational thinking
- [ ] Constructing explanations
- [ ] Engaging in argument from evidence
- [ ] Obtaining, evaluating, and communicating information
- [ ] No science practices observed

5.
Describe instances of science practices observed during the lesson

6.
NGSS Dimension Two: Crosscutting Concepts
Check all that apply.

- [ ] Patterns
- [ ] Cause and effect
- [ ] Scale, proportion, and quantity
- [ ] Systems and system models
- [ ] Energy and matter
- [ ] Structure and function
- [ ] Stability and change
- [ ] No CCC's observed

7.
Describe instances of crosscutting concepts observed during the lesson

8.

NGSS Dimension Three: Disciplinary Core Ideas *

Mark only one oval.

- LS1.A Structure and Function
- LS1.B Growth and Development of Organisms
- LS2.A Interdependent Relationships in Ecosystems
- LS2.B Cycles of Matter and Energy Transfer in Ecosystems
- LS2.C Ecosystem Dynamics, Functioning, and Resilience
- LS2.D Social Interactions and Group Behavior
- LS4.D Biodiversity and Humans
- LS3.A Inheritance of Traits
- LS4.B Variation of Traits
- LS4.A Evidence of Common Ancestry and Diversity
- LS4.B Natural Selection
- LS4.C Adaptation
- LS4.D Biodiversity and Humans
- LS1.C Organization for Matter and Energy Flow in Ecosystems

9.

Select the NGSS performance expectation used in the lesson

Mark only one oval.

- HS-LS1-1. Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.
- HS-LS1-2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.
- HS-LS1-3. Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis
- HS-LS1-4. Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms
- HS-LS1-5. Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy
- HS-LS1-6. Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.
- HS-LS1-7. Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy
- HS-LS2-1. Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales
- HS-LS2-2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales
- HS-LS2-3. Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions
- HS-LS2-4. Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem
- HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere
- HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem
- HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity
- HS-LS2-8. Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce
- HS-LS3-1. Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring

HS-LS3-2. Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors

HS-LS3-3. Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.

HS-LS4-1. Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

HS-LS4-2. Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

HS-LS4-3. Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait

HS-LS4-4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations

HS-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

HS-LS4-6. Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.

No NGSS performance expectation was used in the lesson

10. Describe instances where NGSS PE's were used in the explanation of the lesson's anchoring phenomena/problem

II. Instructional Supports

Instructional Supports

11.

Describe instances where authentic and meaningful scenarios that reflect science practices as experienced in the real world and that provide students with a purpose were used in the lesson.

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12.

Discuss instances where scientifically accurate and grade-appropriate scientific information, phenomena, and representations were used in the lesson to support students' three-dimensional learning.

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13.

What opportunities were evident in the lesson that allowed students to express, clarify, justify, interpret, and represent their ideas and respond to peer and teacher feedback orally and/or in written form as appropriate to student's three- dimensional learning?

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III. Monitoring Student Progress

Student Progress

14.

Describe the type(s) of formative assessments that were used during the lesson.

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15.

Give examples of how concepts learned during the lesson will be incorporated into summative assessments.

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IV. Lesson Reflection

Lesson Reflection

16.

Notable Events: Describe in detail any notable events that occurred during the lesson.

17.

Points of Tension: Did any points of tension emerge during the lesson?

18.

Issues of Control: Were any teacher/student/content issues of control apparent during the lesson?

19.

Excluded content: Was any traditionally taught content excluded due to the format of the lesson?

20.

Instructional Shifts: Were there any noticeable shifts in instruction that occurred during the lesson?

21.

General reflective comments

APPENDIX C. DNA AND CELL DIVISION UNIT - TIMELINE

NGSS Lesson	Lesson Length
The Cell Cycle Movie	**5 days** **Day 1** Stage 1: Identify the task and ask the driving question Stage 2: Student timelines on whiteboards Stage 3: Teacher led discussion of the cell cycle with animation Stage 4: Group cell cycle/timeline comparison and questions Stage 5: Teacher led discussion of stop motion video creation Stage 6: Homework: Cell cycle POGIL **Day 2** Stage 7: Student groups research stop motion movie creation techniques using laptop computers Stage 8: Student groups submit a project proposal on Google Classroom Stage 9: The class develops a common grading rubric for the assignment **Day 3** Stage 10: Movie production and submission on Google Classroom **Day 4** Stage 11: Students present their movies to the class **Day 5** Stage 12: Group and peer movie critiques Stage 13: Student learning extension Stage 14: Teacher/student concept clarification session Stage 15: Homework: What Happens When Mitosis Goes Wrong? (CER – Claim, evidence, reasoning)
Onion Root Tip Lab (Mitosis)	**5 days** **Day 1** Stage 1: Identify task and the guiding question Stage 2: Small groups: Develop a claim discuss evidence collection **Day 2** Stage 3: Argumentation session: round-robin critiques of groups’ claim Stage 4: Students write investigative reports as homework. **Days 3 and 4** Stage 5: Prepare root tip slides

NGSS Lesson	Lesson Length
	Stage 6: Data collection using microscopes Stage 7: Group data collaboration **Day 5** Stage 9: Double-blind group peer review of investigative reports Stage 10: Modify claims and resubmit investigative reports as homework Stage 11: Complete lab reports
How Does the Process of Meiosis Reduce the Number of Chromosome in Reproductive Cells?	**3 days** **Day 1** Stage 1: Identify the task and ask the guiding question Stage 2: Small groups – Design a method and brainstorm meiosis cards to determine sequence of events. Stage 3: Collect data **Day 2** Stage 4: Argumentation session: round-robin meiosis model critiques. Students revise hypothesis about meiosis stages. Stage 5: Students write investigative reports as homework and complete lab checkout sheets. **Day 3** Stage 6: Double-blind group peer review of reports. Stage 7: Teacher led explicit and reflective discussion Stage 8: Crash Course Biology #13 - Meiosis: Where the Sex Starts – https://www.youtube.com/watch?v=qCLmR9-YY7o Stage 9: Homework: Meiosis POGIL, students revise investigative reports.
DNA Structure – What is the Structure of DNA?	**4 days** **Day 1** Stage 1: Identify the task and ask the guiding question Stage 2: Small groups – Design a method and brainstorm model design ideas **Day 2** Stage 3: Data collection – Model construction **Day 3** Stage 4: Argumentation session: model critiques in “round robin” format. Students write investigative reports as homework **Day 4** Stage 5: Double-blind group peer review of reports Stage 6: Teacher led explicit and reflective discussion Show students Crash Course: DNA Structure and Replication: Crash Course Biology #10 https://www.youtube.com/watch?v=8kK2zwjRV0M

NGSS Lesson	Lesson Length
	Homework: DNA Structure and Replication POGIL
DNA Discovery Refutational Writing	**2 days (in class time)** **Days 1 and 2** Stage 1: assignment clarification Stage 2: student research **Day 3:** Stage 3: prewrite (outline, concept map) due as homework on Google Classroom **Day 5** Stage 4: Initial draft of essay due on Google Classroom **Day 7** Stage 5: Teacher returns initial drafts with comments to students via Google Classroom **Day 9** Stage 5: Final draft of essay due on Google Classroom
DNA Extraction Lab & DNA Replication	**3 days** **Day 1** Stage 1: Identify task and driving question Stage 2: Small group research into DNA extraction methods Stage 3: Group decision on materials and procedures for the lab Stage 4: Student groups make a claim as to whether different species have the same or different amounts of DNA in a similar amount of tissue and present the claim to the class. **Day 2** Stage 5: Students follow the agreed upon procedure and extract DNA from two different tissue samples and collect data. Stage 6: Students watch Crash Course #10: DNA structure and replication for homework as a review. https://www.youtube.com/watch?v=2ktAAxV1BZM **Day 3:** Stage 7: Student groups report on their lab results to the rest of the class. Stage 8: Students complete their lab handouts and complete the DNA replication simulation. Stage 9: Teacher shows the video "What is polyploidy" https://www.youtube.com/watch?v=EJVL_qmmqCQ
Transcription & Translation (RNA and Protein Synthesis)	**4 days** **Day 1**

NGSS Lesson	Lesson Length
	Stage 1: Identify the task and ask the driving question. Stage 2: Hand out activity packets and read out albinism. Stage 3: Teacher describes how transcription works. Students answer questions 1-3 on their student handouts. Discuss the answers. Stage 4: Students answer questions 4-5 in their handouts. Discuss the answers. Stage 5: Show the HHMI transcription video: http://www.hhmi.org/biointeractive/dna-transcription-basic-detail Homework: Transcription POGIL **Day 2** Stage 6: Students model transcription by following the instructions on page three of their handouts in groups of two. Stage 7: Students answer questions 6-8 in their handouts. Discuss the answers. Homework: Translation POGIL **Day 3** Stage 8: Introduce and describe translation. Stage 9: Students begin at the top of page five of their handouts and answer question nine. Stage 10: Show the HHMI translation video: http://www.hhmi.org/biointeractive/translation-basic-detail Stage 11: Teacher describes and answers questions about translation. Stage 12: Students answer question 12. Stage 13: Show the translation animation again and have students compare the animation to the figure on page five to reinforce students understanding of the process. Stage 14: Students model translation in groups of two by following the directions on pages 6-8 of the handout. Students answer questions 11-14. **Day 4** Stage 15: Students answer questions 15-20 in the handouts and discuss their answers. Stage 16: Discuss how different alleles result in different versions of a protein which in turn can result in different characteristics. Stage 17: Students answer questions 21-25 and discuss their answers. Stage 18: Show the HHMI sickle cell anemia video: http://www.hhmi.org/biointeractive/sickle-cell-anemia Stage 19: Discuss the video and answer student questions

APPENDIX D. DNA AND CELL DIVISION UNIT EQUIP RUBRIC EVALUATION

EQuIP Rubric for Lessons & Units: Science (Version 3.0)

Reviewer Name or ID: D. Henigman **Grade:** 09 **Lesson/Unit Title:** DNA & Cell Division Unit

Category I: NGSS 3D Design (lessons and units): *The lesson/unit is designed so students make sense of phenomena and/or design solutions to problems by engaging in student performances that integrate the three dimensions of the NGSS.*

<table>
<tr>
<th>Lesson and Unit Criteria
Lessons and units designed for the NGSS include clear and compelling evidence of the following:</th>
<th colspan="2">Specific evidence from materials
(what happened/where did it happen)
and reviewer's reasoning
(how/why is this evidence)</th>
<th>Evidence of Quality?</th>
<th>Suggestions for improvement</th>
</tr>
<tr>
<td>A. Explaining Phenomena/Designing Solutions: Making sense of phenomena and/or designing solutions to a problem drive student learning.
i. Student questions and prior experiences related to the phenomenon or problem motivate sense-making and/or problem solving.
ii. The focus of the lesson is to support students in making sense of phenomena and/or designing solutions to problems.
iii. When engineering is a learning focus, it is integrated with developing disciplinary core ideas from physical, life, and/or earth and space sciences.</td>
<td colspan="2">While this unit uses many SEP's that are NGSS aligned, the unit fails to combine SEP's, CCC's, and DCI's into a coherent unit that is has a driving problem or phenomena that unites the unit. As a result, students learn the DCI's in a disjointed manner that does not allow them to investigate DNA and Cell Division in a three-dimensional learning environment. The compartmentalization of this unit prevents students from engaging in real three-dimensional learning. There are guiding questions within each activity, but not in the unit as a whole.</td>
<td>☐ None
☒ Inadequate
☐ Adequate
☐ Extensive</td>
<td>Redesign the unit to embed a real-life scenario, problem, or phenomena that drives and unites the unit. This will better allow for three-dimensional learning and design solutions to the problem or phenomena.</td>
</tr>
<tr>
<td>B. Three Dimensions: Builds understanding of multiple grade-appropriate elements of the science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCCs) that are deliberately selected to aid student sense-making of phenomena and/or designing of solutions.</td>
<td>Document evidence and reasoning, and evaluate whether or not there is sufficient evidence of quality for each dimension separately</td>
<td>Evidence of Quality?</td>
<td rowspan="4">☐ None
☐ Inadequate
☒ Adequate
☐ Extensive

(All 3 dimensions must be rated at least "adequate" to mark "adequate" overall)</td>
<td rowspan="4">While the three-dimensions are represented adequately in this unit, they are not integrated throughout the unit in a cohesive manner. The unit is disjointed and a redesign must be made to incorporate a guiding problem or phenomena in order to unify three-dimensional learning throughout the unit. With these changes, this unit has the potential to become an NGSS aligned unit of instruction.</td>
</tr>
<tr>
<td>i. Provides opportunities to develop and use specific elements of the SEP(s).</td>
<td>i.
Asking questions and defining problems, developing and using models,engaging in argument from evidence, constructing explanations, obtaining evaluating and communicating informaiton</td>
<td>☐ None
☐ Inadequate
☒ Adequate
☐ Extensive</td>
</tr>
<tr>
<td>ii. Provides opportunities to develop and use specific elements of the DCI(s).</td>
<td>ii.
LS1.A, LS3.A, LS3.B are adequately covered in this unit.</td>
<td>☐ None
☐ Inadequate
☒ Adequate
☐ Extensive</td>
</tr>
<tr>
<td>iii. Provides opportunities to develop and use specific elements of the CCC(s).

Evidence needs to be at the element level of the dimensions (see rubric introduction for a description of what is meant by "element")</td>
<td>iii.
Patterns, Cause and effect, Scale, proportion, and quantity, systems & system models, structure and function</td>
<td>☐ None
☐ Inadequate
☒ Adequate
☐ Extensive</td>
</tr>
</table>

C. **Integrating the Three Dimensions:** Student sense-making of phenomena and/or designing of solutions requires student performances that integrate elements of the SEPs, CCCs, and DCIs.	Phenomena and/or problems are evident in this unit, however, they exist within each activity and not within the unit as a whole.	☐ None ☒ Inadequate ☐ Adequate ☐ Extensive	Redesign the unit with the biology PLC and come up with a guiding problem or phenomena that drives the unit.
Rating for Category I. NGSS 3D Design—*lessons* After carefully weighing the evidence, reasoning, and suggestions for improvement, rate the degree to which there is enough evidence to support a claim that the lesson meets these criteria. ***If you are evaluating an instructional unit rather than a single lesson, continue on to evaluate criteria D-F and rate Category I overall below.***	***Lesson* Rating scale for Category I (Criteria A–C only):** 3: Extensive evidence to meet at least two criteria (and at least adequate evidence for the third) 2: Adequate evidence to meet all three criteria in the category 1: Adequate evidence to meet at least one criterion in the category, but insufficient evidence for at least one other criterion 0: Inadequate (or no) evidence to meet any of the criteria in the category		**Select Rating** 0 ○ 1 ◉ 2 ○ 3 ○ After rating the lesson, read below for next steps

<u>What's next if the lesson rating is less than a 2?</u>

*If the rubric is being used to approve or vet resources and the lesson or unit does not score at least a "2" in **Category I: NGSS 3D Designed**, the review should stop and feedback should be provided to the lesson developer(s) to guide revisions. If the rubric is being used locally for revising and building lessons, professional judgment should guide whether to continue reviewing the lesson. Categories II and III may be time consuming to evaluate if Category I has not been met and the feedback may not be useful if significant revisions are needed in Category I, but evaluating these criteria in a group may support deeper and more common understanding of the criteria in these categories and more complete feedback to the lesson developer (if they are not in the room) so that Categories II and III are more likely to be met with fewer cycles of revision.*

<u>What's next if the lesson rating is a 2 or 3?</u>

If you are evaluating a lesson that shows sufficient evidence of quality to warrant a rating of either a 2 or a 3 for Category I, proceed to Category II: NGSS Instructional Supports

Category Ratings:

Transfer your team's ratings from each category to the following chart and add the scores together for the overall score:

Category ratings			
Category I: NGSS 3D Design	**Category II: NGSS Instructional Supports**	**Category III: Monitoring NGSS Student Progress**	**Total Score**
0 1 2 3	0 1 2 3	0 1 2 3	1

Overall ratings: The score total is an *approximate* guide for the rating. Reviewers should use the evidence of quality across categories to guide the final rating. In other words, the rating could differ from the total score recommendations if the reviewer has evidence to support this variation.	**E: Example of high quality NGSS design**—High quality design for the NGSS across all three categories of the rubric; a lesson or unit with this rating will still need adjustments for a specific classroom, but the support is there to make this possible; exemplifies most criteria across Categories I, II, & III of the rubric. (total score ~8–9) **E/I: Example of high quality NGSS design if Improved**—Adequate design for the NGSS, but would benefit from some improvement in one or more categories; most criteria have at least adequate evidence (total score ~6–7) **R: Revision needed**—Partially designed for the NGSS, but needs significant revision in one or more categories (total ~3–5) **N: Not ready to review**—Not designed for the NGSS; does not meet criteria (total 0–2)	**Select the overall rating below:** **E** **E/I** **R** **N**

APPENDIX E. PROJECT NEURON UNIT OUTLINE

From the Project Neuron Unit "What makes me tick…tock? Circadian rhythms, genetics, and health, 2016. (https://neuron.illinois.edu/units/what-makes-me-tick-tock).

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project NEURON

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What makes me tick...tock?
Circadian rhythms, genetics, and health

Lesson 1: What is a circadian rhythm?

In this introductory lesson to the unit, students conduct an in-class survey to learn about the circadian rhythms and biological clocks of their peers. Using this survey, students identify the owls and the larks in their classroom. In addition, students generate questions related to what they would like to know or learn about biological rhythmicity. These questions will be generated as a whole class and will be referred back to in the upcoming lessons. At the end of the lesson, they learn about some concepts related to circadian rhythms as they watch a video.

Lesson 2: Why do scientists study fruit flies to find what makes us "tick"?

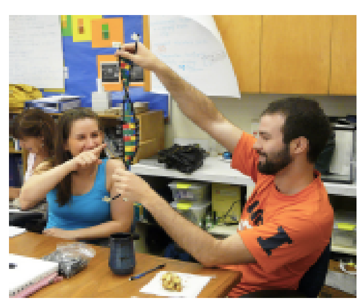
Following the introduction of basic principles and key terminology of circadian rhythmicity in Lesson 1, this lesson begins with students discussing model organisms and how scientists use them; *Drosophila melanogaster* is used as a model for the study of circadian rhythms. Students also use four NetLogo models to examine how light affects a fly's behavior. Students make connections between these models and the length of daylight.

Lesson 3: How can genetics change your clock?

The goal of this lesson is to teach the students about how changes to circadian genes can have physiological affects that may or not have circadian phenotypes. Students construct a model of a circadian gene, Period 2 (per2). Using this model, students explain how changes in the nucleic acid sequence can change protein structure and, ultimately, alter protein function.

Lesson 4: Tick tock...Broken clock

Using a case study format, students investigate the source of a fictional character's sleeping problems. Students are presented with information that they must utilize to progress through four "checkpoints" throughout the course of the lesson. Each checkpoint will give the student groups access to additional information based on current research regarding the nature of the patent's sleep difficulties. This information is presented as records collected by a hospital case investigation team for review by the students as case investigators. After completing all of the checkpoints in the order of their choosing, students teams to come to a final consensus on the patient's diagnosis.



September 2013

What makes me tick…tock?
Circadian rhythms, genetics, and health

Lesson 5: How do environment and modern society influence our rhythms?

Students apply what they have learned about circadian processes to issues relevant to human light exposure, species biology and ecology. Students use light meters to examine light exposure differences around their school to illustrate the possible influences of habitat/workplace on light exposure, and they read and discuss a series of short articles that exemplify the interaction between environment and circadian rhythms. Through these two activities, students explore how cues from the environment entrain their biological daily clocks. In addition, they examine examples of how endogenous circadian clocks in different species have adapted over time to allow the species to survive in their light environment.

Lesson 6: What happens to humans when normal rhythms are disrupted?

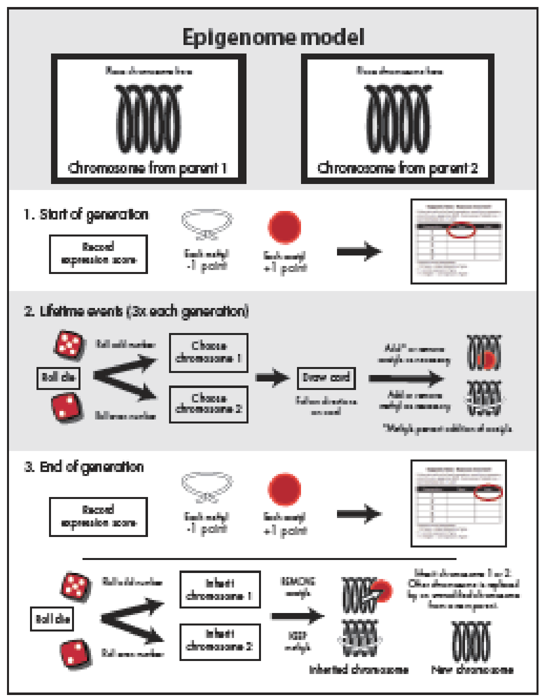
This lesson focuses on the circadian rhythm and its connection to humans. Students will analyze the average results of their sleepiness scale and compare it to others. They will examine multiple instances where circadian rhythms have an impact on real life scenarios in humans. This lesson will be applicable to the students' lives and will consist of topics that they are familiar with.

Lesson 7: How can epigenetics change your clock?

The goal of this lesson is to teach the students about how changes to circadian genes can have physiological affects that may or not have circadian phenotypes. Using the period 2 gene sequence, students will play the Epigenome Game to learn about how changing the secondary structure of DNA can up- or down-regulate expression of genes.

Lesson 8: When should the school day begin?

During this lesson, students debate the most appropriate starting time of the school day using the relevant information learned throughout the unit as their evidence for claims they make. Groups will be required to pull from knowledge they acquired from throughout the unit, including sleepiness scale data and experimental results, as well as information gathered from popular media and scientific journal articles, to formulate their argument.



October 2012

What makes me tick...tock?

Circadian rhythms, genetics, and health

Lesson 1: What is a circadian rhythm?

I. Overview

In this introductory lesson to the unit, students conduct an in-class survey to learn about the circadian rhythms and biological clocks of their peers. Using this survey, students identify the owls and the larks in their classroom. In addition, students look at two different Sleepiness Scales as a whole class and interpret the sleep-wake cycles of two people, looking at their sleepiness scales. In addition, they write or draw what they currently know about circadian rhythms and generate questions related to what they would like to know or learn about biological rhythmicity. The students will confirm or refute their ideas based on knowledge gained through a variety of activities and readings in later lessons of the unit. At the end of the lesson, they learn about some concepts related to circadian rhythms as they watch a video about Michel Siffre, a French scientist who studied his own circadian rhythm.

Connections to the driving question

The driving question is introduced in Lesson 1. At the end of the lesson, students try to answer the driving question *What makes me tick...tock?* and *What makes me sleep?* by coming up with their own hypotheses to explain possible biological clocks. Students are asked to illustrate their theory with a drawing or by writing a short paragraph. Throughout the unit, as students learn new information to answer the driving question, they will refer back to their hypotheses to confirm, readjust or reject them.

II. Standards/Benchmarks

National Education Science Standards

Content Standard A: Abilities necessary to do scientific inquiry

- Students should formulate a testable hypothesis and demonstrate the logical connections between the scientific concepts guiding a hypothesis and the design of an experiment. They should demonstrate appropriate procedures, a knowledge base, and conceptual understanding of scientific investigations (9-12 A: 1/1).

Content Standard C: The Behavior of Organisms

- Organisms have behavioral responses to internal changes and to external stimuli. Responses to external stimuli can result from interactions with the organism's own species and others, as well as environmental changes; these responses either can be innate or learned. The broad patterns of behavior exhibited by animals have evolved to ensure reproductive success. Animals often

October 2012

What makes me tick…tock?

Circadian rhythms, genetics, and health

Lesson 2: Why do scientists study fruit flies to understand what makes us "tick"?

I. Overview

Following the introduction of basic principles and key terminology of circadian rhythmicity in Lesson 1, this lesson begins with students discussing model organisms and how scientists use them; *Drosophila melanogaster* is used as a model for the study of circadian rhythms. Students use several NetLogo simulations to examine how light, temperature, and genetic mutations can affect a fly's behavior. Students make connections between these simulations and their own circadian rhythms, developing models throughout the lesson of how three different factors (light, temperature, and genetic mutations) can affect both the flies' activity levels and their own throughout the day.

Connections to the driving question

This lesson allows students to use a model to address the driving question, collecting data to draw conclusions on what drives our circadian rhythms. The created models allow students to analyze how environmental influences and genetics can impact an organism's circadian rhythm. This information is then applied to their own lives in a concluding discussion at the end of the lesson.

Connections to the previous lesson

In the previous lesson, the students generated ideas and hypotheses regarding what impacts the circadian rhythms as well as what the circadian rhythm impacts in daily life. Also, they use an experimental model, the fruit fly to examine how light/dark cycles impact circadian rhythms, similar to the experiment Michel Siffre performed on himself in the cave.

II. Standards/Benchmarks

National Science Education Standards

Content Standard A: Abilities necessary to do scientific inquiry

- Identify questions and concepts that guide scientific investigations. Students should formulate a testable hypothesis and demonstrate the logical connections between the scientific concepts guiding a hypothesis and the design of an experiment. They should demonstrate appropriate procedures, a knowledge base, and conceptual understanding of scientific investigations. (9-12 A: 1/1)
- Formulate and revise scientific explanations and models using logic and evidence. Student inquiries should culminate in formulating an explanation or model. Models should be physical,

October 2012

What makes me tick...tock?

Circadian rhythms, genetics, and health

Lesson 3: How can genetics change your clock?

I. Overview

The goal of this lesson is to teach the students about how changes to circadian genes can have physiological effects that may or may not have circadian phenotypes. Students construct a physical model of a circadian gene, Period 2 (*per2*). Using this model, students explain how changes in the nucleic acid sequence can change protein structure and, ultimately, alter protein function.

Connection to the Driving Question

In this lesson, students are introduced to the Period 2 gene, a gene involved in the control of circadian rhythms, and the role that genetics play in an individual's circadian rhythms. This lesson also serves as an introduction to concepts about DNA and proteins that the students use in Lesson 4 when they do a case study about an individual with disrupted sleep patterns.

Connection to the Previous Lesson

In the previous lesson, students observed a model organism's change in circadian rhythm due to external cues. They ended the lesson investigating *per* gene mutations and how those mutations affected the flies' circadian rhythms. In this lesson, students look more in depth at how the *per2* gene mutations affect the molecular structure of the PER2 protein, and how that change in structure leads to a change in behavior.

II. Standards/Benchmarks

National Science Education Standards

Content Standard C: Structure and Function in Living Systems

- Disease is a breakdown in structures or functions of an organism. Some diseases are the result of intrinsic failures of the system. Others are the result of damage by infection by other organisms. (5-8 C: 1/6)

Content Standard C: The Cell

- Cells store and use information to guide their functions. The genetic information stored in DNA is used to direct the synthesis of the thousands of proteins that each cell requires. (9-12 C: 1/3)

Content Standard C: The Molecular Basis of Heredity

October 2012

What makes me tick…tock?

Circadian rhythms, genetics, and health

Lesson 4: Tick tock…Broken clock

I. Overview

In this lesson, students learn about the role played by DNA and proteins in the circadian cycle. Students also explore some of the scientific and diagnostic techniques used by doctors and researchers to diagnose and study circadian rhythm disorders. Using a case study format, students investigate the source of a fictional character's sleeping problems. Students are presented with information that they must utilize to progress through four "checkpoints" throughout the course of the lesson. Each checkpoint gives student groups access to additional information based on current research regarding the nature of the patient's sleep difficulties. The students, who act as case investigators, review records collected by a hospital case investigation team to help solve the young man's sleeping problems.

After completing all of the checkpoints in the order of their choosing, each group will regroup as possible "diagnoses" teams, where each group member gains in-depth knowledge of a possible diagnosis for the patient. Following this jigsaw, students return to their investigation teams to come to a final consensus on the patient's diagnosis.

Connection to the Driving Question

In this lesson, students address what happens when someone's "clock" is disrupted due to a genetic disorder. Thus, students use data that has been generated about circadian rhythms to determine how the processes that make us "tick…tock" can be altered and cause problems with our circadian rhythms.

Connection to the Previous Lesson

Lesson 4 builds upon the core concepts established in Lesson 3. Lesson 4 requires students to take their new knowledge of the PER2 gene and apply it interpret the scientific information presented in the case study. In Lesson 4, students compare the DNA sequences of a mutated and non-mutated *per* gene and then transcribe and translate the sequences to verify any changes to the amino acid sequence. Students also utilize their knowledge of protein structure to aid them in interpreting Western blot results to insight into the cyclical nature of the PER2 gene.

II. Standards/Benchmarks

National Science Education Standards

Content Standard C: The Cell

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What makes me tick…tock?

Circadian rhythms, genetics and health

Lesson 5: How do environment and modern society influence our rhythms?

I. Overview

In this lesson, students apply what they have learned about circadian processes to issues relevant to human light exposure, species biology and ecology. Students use light meters to examine light exposure differences around their school to illustrate the possible influences of habitat/workplace on light exposure. Students read and discuss a series of short articles that exemplify the interaction between environment and circadian rhythms. Students develop a scientific explanation to answer the question: Does environment influence circadian rhythms? Through these activities, students explore how cues from the environment entrain their biological daily clocks. In addition, they examine examples of how endogenous circadian clocks in different species have adapted over time to allow the species to survive in their light environment.

Connections to the Driving Question

In this lesson, students investigate how the environment, particularly exposure to light, can affect the circadian rhythm. Students look at external cues that can cause changes to the circadian rhythm, as opposed to internal gene and protein expression studied in previous lessons.

Connections to the Previous Lesson

In the previous lesson, students examine how changes to one's internal structures, such as DNA and protein, lead to changes in sleep patterns. Now, students look at how light exposure can affect both humans' and animals' circadian rhythms. This is an external cue, or zeitgeiber that has caused the animals to evolve in a particular direction to be better suited for their environment. Thus, the external environment selected for particular gene expression, leading to changes in the animals' internal clock.

II. Standards/ Benchmarks

National Science Education Standards

Content Standard C: The Behavior of Organisms

- Organisms have behavioral responses to internal changes and to external stimuli. Responses to external stimuli can result from interactions with the organism's own species and others, as well as environmental changes; these responses either can be innate or learned. The broad patterns of behavior exhibited by animals have evolved to ensure reproductive success. Animals often

October 2012

What makes me tick…tock?

Circadian rhythms, genetics, and health

Lesson 6: What happens to humans when normal rhythms are disrupted?

I. Overview:

This lesson focuses on the circadian rhythm and its connection to humans. Students analyze the average results of their sleepiness scales started in Lesson 1 and compare it to others in the class. They examine multiple instances where circadian rhythms have an impact on real life scenarios in humans. This lesson will be applicable to the students' lives and will consist of topics that they are familiar with.

Connections to the Driving Question

In order to truly understand what makes us "tick," it is important to discover what happens when something is disrupted. This lesson encourages students to discuss what can happen when our "tick" is no longer in its normal rhythm. It even asks students to address possible solutions that can keep the rhythm consistent within certain work and environmental conditions.

Connections to the Previous Lesson

In the previous lesson, students examined how light exposure can change the circadian rhythms of humans and other animals. Now, they look at adverse complications of circadian rhythm disruptions on human health, focusing on humans with occupations that lead to abnormal light exposure.

II. Standards/Benchmarks

National Education Science Standards

Content Standard A: Understandings about Scientific Inquiry

- Results of scientific inquiry-new knowledge and methods-emerge from different types of investigations and public communication among scientists. In communicating and defending the results of scientific inquiry, arguments must be logical and demonstrate connections between natural phenomena, investigations, and the historical body of scientific knowledge. In addition, the methods and procedures that scientists used to obtain evidence must be clearly reported to enhance opportunities for further investigation. (9-12 A: 2/6)

Content Standard C: The Behavior of Organisms

- Organisms have behavioral responses to internal changes and external stimuli. Responses to external stimuli can result from interactions with the organism's own species and others, as well as environmental changes; these responses can either be innate or learned. The broad patterns

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What makes me tick...tock?

Circadian rhythms, genetics, and health

Lesson 7: How can epigenetics change your clock?

I. Overview

The goal of this lesson is to teach students about how changes to circadian genes can have physiological effects that may or may not have circadian phenotypes. Using the period 2 gene sequence, students will play the Epigenome game to learn about how changing the secondary structure of DNA can up- or down-regulate expression of genes.

Connection to the Driving Question

In this lesson, the students learn how environmental and lifestyle factors change the shape of the chromosomes. This change to the structure of the DNA can cause genes to be more or less likely to be expressed. This lesson serves to connect how the environment and behavior/lifestyle can affect the expression of circadian rhythm genes, which in turn can alter circadian rhythms.

Connection to the Previous Lesson

In the previous lesson, the students examined how a variety of careers/jobs can impact one's circadian rhythm and have secondary health effects due to these disruptions in the circadian rhythm. Now, students explore the idea of lifestyle choices further by investigating the epigenome, or how chromosome structure can change causing changes in gene expression. Students should now be able to explain how changes in gene expression, protein structures and/or expression levels can lead to changes in behavior and/or physiology.

II. Standards/Benchmarks

National Science Education Standards

Content Standard C: Structure and Function in Living Systems

- Disease is a breakdown in structures or functions of an organism. Some diseases are the result of intrinsic failures of the system. Others are the result of damage by infection by other organism (5-8 C: 1/3).

Content Standard C: The Cell

- Cells store and use information to guide their functions. The genetic information stored in DNA is used to direct the synthesis of the thousands of proteins that each cell requires. (9-12 C: 1/3)

Content Standard C: The Molecular Basis of Heredity

What makes me tick…tock?

Circadian rhythms, genetics, and health

Lesson 8: When should the school day begin?

I. Overview

During this lesson, students debate the most appropriate starting time of the school day using the relevant information learned throughout the unit as their evidence for claims they make. Students work in groups to create an argument for what they believe to be the best starting time for the school day, share their argument with the class in the form of a discussion/debate, and prepare a presentation to share their recommendation for school day starting time with a school administrator. Groups will be required to pull from knowledge they acquired from throughout the unit, including sleepiness scale data and experimental results, as well as information gathered from popular media and scientific journal articles, to formulate their argument.

Connections to the Driving Question

This final lesson has the students take what they have learned in Lessons 1-7, in regards to what makes us "tick…tock" and apply it to a real life situation, such as the start time of the school day. Their argument for when the school day should start bases itself on the ideas throughout the unit.

Connections to the Previous Lesson

In the previous lesson, students explored how lifestyle choices can affect the epigenome, or alter the structure of chromosomes. Now, the students take what they have learned from this lesson and apply it, along with ideas from Lessons 1-6, to construct an argument on what time school should start. Epigenetic changes are one piece of evidence the students can use to construct their argument for an earlier or later school start time.

II. Standards/Benchmarks

National Education Science Standards

Content Standard A: Science as Inquiry

- Students in school science programs should develop the abilities associated with accurate and effective communication. These include writing and following procedures, expressing concepts, reviewing information, summarizing data, using language appropriately, developing diagrams and charts, explaining statistical analysis, speaking clearly and logically, constructing a reasoned argument, and responding appropriately to critical comments. (9-12 A: 1/6)

Benchmarks for Science Literacy

APPENDIX F. WHAT MAKES ME TICK…TOCK EQUIP RUBRIC ANALYSIS

EQuIP Rubric for Lessons & Units: Science (Version 3.0)

Reviewer Name or ID: D. Henigman **Grade:** 09 **Lesson/Unit Title:** Project Neuron: What makes me tick>..tock? Unit

Category I: NGSS 3D Design (lessons and units): *The lesson/unit is designed so students make sense of phenomena and/or design solutions to problems by engaging in student performances that integrate the three dimensions of the NGSS.*

<table>
<tr>
<th>Lesson and Unit Criteria
Lessons and units designed for the NGSS include clear and compelling evidence of the following:</th>
<th colspan="2">Specific evidence from materials
(what happened/where did it happen)
and reviewer's reasoning
(how/why is this evidence)</th>
<th>Evidence of Quality?</th>
<th>Suggestions for improvement</th>
</tr>
<tr>
<td>A. Explaining Phenomena/Designing Solutions: Making sense of phenomena and/or designing solutions to a problem drive student learning.
i. Student questions and prior experiences related to the phenomenon or problem motivate sense-making and/or problem solving.
ii. The focus of the lesson is to support students in making sense of phenomena and/or designing solutions to problems.
iii. When engineering is a learning focus, it is integrated with developing disciplinary core ideas from physical, life, and/or earth and space sciences.</td>
<td colspan="2">Student learning is driven by investigating the question: What makes me tick..tock? Circadian rhythms is the phenomenon that drives the storyline in this unit. Students investigate various aspects of circadian rhythms during the lessons to ultimately answer the question in lesson 8: When should the school day begin?</td>
<td>☐ None
☐ Inadequate
☐ Adequate
☒ Extensive</td>
<td>Give a detailed explanation of phenomena based learning at the beginning of the unit and how it supports 3D learning.</td>
</tr>
<tr>
<td>B. Three Dimensions: Builds understanding of multiple grade-appropriate elements of the science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCCs) that are deliberately selected to aid student sense-making of phenomena and/or designing of solutions.</td>
<td>Document evidence and reasoning, and evaluate whether or not there is sufficient evidence of quality for each dimension separately</td>
<td>Evidence of Quality?</td>
<td rowspan="4">☐ None
☒ Inadequate
☐ Adequate
☐ Extensive

(All 3 dimensions must be rated at least "adequate" to mark "adequate" overall)</td>
<td rowspan="4">Have a unit master list of SEP's used in the unit, and where they are used in the unit introduction. Align the lesson in the unit to the NGSS life science DCI's and PE's. Include them with the SEP's and CCC's at the beginning of the unit, and within each lesson. Analyze the unit to Identify the CCC's in each lesson.</td>
</tr>
<tr>
<td>i. Provides opportunities to develop and use specific elements of the SEP(s).</td>
<td>i.
Many of the units' lessons incorporate a science practice. For example, In lesson 1, the science practice: Planning and carrying out an investigation is used. Lesson 2 uses the SEP: developing the using models. Lesson 4 uses the SEP: analyzing and interpreting data, and so on.</td>
<td>☐ None
☐ Inadequate
☐ Adequate
☒ Extensive</td>
</tr>
<tr>
<td>ii. Provides opportunities to develop and use specific elements of the DCI(s).</td>
<td>ii.
The unit was written prior to the NGSS and uses the NSES content standards, and the AAAS benchmarks, instead of the NGSS life science DCI's</td>
<td>☐ None
☒ Inadequate
☐ Adequate
☐ Extensive</td>
</tr>
<tr>
<td>iii. Provides opportunities to develop and use specific elements of the CCC(s).

Evidence needs to be at the element level of the dimensions (see rubric introduction for a description of what is meant by "element")</td>
<td>iii.
The NGSS CCC's are not identified in the lesson, although through analysis of each unit they could be identified.</td>
<td>☐ None
☒ Inadequate
☐ Adequate
☐ Extensive</td>
</tr>
</table>

C. **Integrating the Three Dimensions:** Student sense-making of phenomena and/or designing of solutions requires student performances that integrate elements of the SEPs, CCCs, and DCIs.	I believe that integration of the three-dimensions would be evident upon close evaluation and conversion of the unit from NSES and AAAS standards to the NGSS. SEP's are evident in the unit, and the unit has the potential to be a well designed phenomena based unit.	☐ None ☒ Inadequate ☐ Adequate ☐ Extensive	Align the unit to the NGSS CCC's and DCI's. Identify the NGSS PE's in the unit.
Rating for Category I. NGSS 3D Design—*lessons* After carefully weighing the evidence, reasoning, and suggestions for improvement, rate the degree to which there is enough evidence to support a claim that the lesson meets these criteria. ***If you are evaluating an instructional unit rather than a single lesson, continue on to evaluate criteria D-F and rate Category I overall below.***	***Lesson* Rating scale for Category I (Criteria A–C only):** 3: Extensive evidence to meet at least two criteria (and at least adequate evidence for the third) 2: Adequate evidence to meet all three criteria in the category 1: Adequate evidence to meet at least one criterion in the category, but insufficient evidence for at least one other criterion 0: Inadequate (or no) evidence to meet any of the criteria in the category		**Select Rating** **0 1 2 3** ○ ◉ ○ ○ After rating the lesson, read below for next steps

<u>What's next if the lesson rating is less than a 2?</u>
*If the rubric is being used to approve or vet resources and the lesson or unit does not score at least a "2" in **Category I: NGSS 3D Designed**, the review should stop and feedback should be provided to the lesson developer(s) to guide revisions. If the rubric is being used locally for revising and building lessons, professional judgment should guide whether to continue reviewing the lesson. Categories II and III may be time consuming to evaluate if Category I has not been met and the feedback may not be useful if significant revisions are needed in Category I, but evaluating these criteria in a group may support deeper and more common understanding of the criteria in these categories and more complete feedback to the lesson developer (if they are not in the room) so that Categories II and III are more likely to be met with fewer cycles of revision.*

<u>What's next if the lesson rating is a 2 or 3?</u>
If you are evaluating a lesson that shows sufficient evidence of quality to warrant a rating of either a 2 or a 3 for Category I, proceed to Category II: NGSS Instructional Supports

Category I: NGSS 3D Design (additional criteria *for units only*):

If you are evaluating a lesson, it is not necessary to evaluate criteria D–F. Please enter your rating for a single lesson above (after C).

Unit Criteria A unit or longer lesson designed for the NGSS will also include clear and compelling evidence of the following:	**Specific evidence from materials and reviewers' reasoning**	**Evidence of Quality?**	**Suggestions for improvement**
D. **Unit Coherence**: Lessons fit together to target a set of performance expectations. i. Each lesson builds on prior lessons by addressing questions raised in those lessons, cultivating new questions that build on what students figured out, or cultivating new questions from related phenomena, problems, and prior student experiences. ii. The lessons help students develop toward proficiency in a targeted set of performance expectations.	NGSS performance expectations are not used in the unit, however, with analysis, the NGSS PE's could be identified. Each lesson does build on prior lessons knowledge and understanding of the phenomena.	☐ None ☒ Inadequate ☐ Adequate ☐ Extensive	Align the unit to the NGSS PE's
E. **Multiple Science Domains**: *When appropriate*, links are made across the science domains of life science, physical science and Earth and space science. i. Disciplinary core ideas from different disciplines are used together to explain phenomena. ii. The usefulness of crosscutting concepts to make sense of phenomena or design solutions to problems *across science domains* is highlighted.	DCI's from other domains are not indicated in the unit. 3	☒ None ☐ Inadequate ☐ Adequate ☐ Extensive	Integrate DCI's from other disciplines, and identify CCC's that could be used to investigate the phenomenon across domains.
F. **Math and ELA:** Provides grade-appropriate connection(s) to the Common Core State Standards in Mathematics and/or English Language Arts & Literacy in History/Social Studies, Science and Technical Subjects.	None observed	☒ None ☐ Inadequate ☐ Adequate ☐ Extensive	Analyze the unit to include math and ELA standards
Rating for Category I. NGSS 3D Designed—*units* After carefully weighing the evidence, reasoning, and suggestions for improvement, rate the degree to which the criteria are met across the unit.	**Unit Rating Scale for Category I (Criteria A–F):** 3: At least adequate evidence for all of the unit criteria in the category; extensive evidence for criteria A–C 2: At least some evidence for all unit criteria in Category I (A–F); adequate evidence for criteria A–C 1: Adequate evidence for some criteria in Category I, but inadequate/no evidence for at least one criterion A–C 0: Inadequate (or no) evidence to meet any criteria in Category I (A–F)		**Select Rating** 0 ○ 1 ◉ 2 ○ 3 ○

Category II: NGSS Instructional Supports (lessons and units): *The lesson/unit supports three-dimensional teaching and learning for ALL students by placing the lesson in a sequence of learning for all three dimensions and providing support for teachers to engage all students.*

Lesson *and* Unit Criteria Lessons and units designed for the NGSS include clear and compelling evidence of the following:	**Specific evidence from materials and reviewers' reasoning**	**Evidence of Quality?**	**Suggestions for improvement**
A. **Relevance and Authenticity:** Engages students in authentic and meaningful scenarios that reflect the practice of science and engineering as experienced in the real world. i. Students experience phenomena or design problems as directly as possible (firsthand or through media representations). ii. Includes suggestions for how to connect instruction to the students' home, neighborhood, community and/or culture as appropriate. iii. Provides opportunities for students to connect their explanation of a phenomenon and/or their design solution to a problem to questions from their own experience.	Students experience the phenomenon of circadian rhythms through a variety of methods including; investigations, collecting sleep pattern data, using model organisms, model genes, case studies, data analysis, building models, and readings. Each new lesson is conceptually connected to the prior lesson.	☐ None ☐ Inadequate ☐ Adequate ☒ Extensive	Include a chart in the unit introduction that diagrams how the phenomenon flows and integrates into each lesson.
B. **Student Ideas:** Provides opportunities for students to express, clarify, justify, interpret, and represent their ideas and respond to peer and teacher feedback orally and/or in written form as appropriate.	Student ideas are expressed through conversations about the phenomenon in their groups, and through teacher interactions with groups. Additionally, students fill out surveys and answer questions in classwork and homework assignments.	☐ None ☐ Inadequate ☐ Adequate ☒ Extensive	None
C. **Building Progressions:** Identifies and builds on students' prior learning <u>in all three dimensions</u>, including providing the following support to teachers: i. Explicitly identifying prior student learning expected for all three dimensions ii. Clearly explaining how the prior learning will be built upon.	Prior student learning is built on progressively throughout the lessons, however, without NGSS DCI and CCC alignment, it is difficult to tie this into 3D learning.	☐ None ☒ Inadequate ☐ Adequate ☐ Extensive	Align the unit to the NGSS CCC's and DCI's to better allow for 3D learning progression identification.

D. **Scientific Accuracy:** Uses scientifically accurate and grade-appropriate scientific information, phenomena, and representations to support students' three-dimensional learning.	The accuracy of the scientific information in this unit is impressive and there are advanced biological concepts introduced in the unit that are appropriate to accelerated biological learning. Some of these concepts include epigenetics, DNA structure, protein synthesis and structure, actograms, RNA structure and transcription, and much more.	☐ None ☐ Inadequate ☐ Adequate ☒ Extensive	Include interactive videos of DNA replication, transcription, and translation into the lessons.
E. **Differentiated Instruction:** Provides guidance for teachers to support differentiated instruction by including: i. Appropriate reading, writing, listening, and/or speaking alternatives (e.g., translations, picture support, graphic organizers, etc.) for students who are English language learners, have special needs, or read well below the grade level. ii. Extra support (e.g., phenomena, representations, tasks) for students who are struggling to meet the targeted expectations. iii. Extensions for students with high interest or who have already met the performance expectations to develop deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts.	Each lesson contains a section on how the lesson can be adapted, and how accommodations can be made, but this is mainly with respect to procedural issues, and not indications for learner scaffolding.	☐ None ☒ Inadequate ☐ Adequate ☐ Extensive	Provide suggestions for accommodating students with special needs.
Rating for Category II: Instructional Supports—lessons After carefully weighing the evidence, reasoning, and suggestions for improvement, rate the degree to which the lesson met this category. ***If you are evaluating an instructional unit rather than a single lesson, continue on to evaluate criteria F–G and rate Category II overall below.***	**Lesson Rating scale for Category II (Criteria A-E only):** **3**: At least adequate evidence for all criteria in the category; extensive evidence for at least one criterion **2**: Some evidence for all criteria in the category and adequate evidence for at least four criteria, including A **1**: Adequate evidence of quality for at least two criteria in the category **0**: Adequate evidence of quality for no more than one criterion in the category		**Select Rating** **0 1 2 3** ○ ○ ○ ○

Category II: NGSS Instructional Supports (additional criteria *for units only*)

If you are evaluating a lesson, it is not necessary to evaluate criteria F–G. Please enter your rating for a lesson above (after E).

Unit Criteria A unit or longer lesson designed for the NGSS will also include clear and compelling evidence of the following:	**Specific evidence from materials and reviewers' reasoning**	**Evidence of Quality?**	**Suggestions for improvement**
F. **Teacher Support for Unit Coherence:** Supports teachers in facilitating coherent student learning experiences over time by: i. Providing strategies for linking student engagement across lessons (e.g. cultivating new student questions at the end of a lesson in a way that leads to future lessons, helping students connect related problems and phenomena across lessons, etc.). ii. Providing strategies for ensuring student sense-making and/or problem-solving is linked to learning in all three dimensions.	The unit provides extensive teacher support in linking student engagement across lessons through the use of well written questions in each lesson.	☐ None ☐ Inadequate ☐ Adequate ☒ Extensive	None
G. **Scaffolded differentiation over time:** Provides supports to help students engage in the practices as needed and gradually adjusts supports over time so that students are increasingly responsible for making sense of phenomena and/or designing solutions to problems.	Scaffolding differentiation is evident throughout the unit. For example, each lesson builds on aspects of the phenomenon that eventually allow students to design a solution to the problem.	☐ None ☐ Inadequate ☐ Adequate ☒ Extensive	None
Rating for Category II: NGSS Instructional Supports—*units* After carefully weighing the evidence, reasoning, and suggestions for improvement, rate the degree to which the criteria are met across the unit.	***Unit* rating scale for Category II (Criteria A-G):** 3: At least adequate evidence for all criteria in the category; extensive evidence for at least two criteria 2: Some evidence for all criteria in the category and adequate evidence for at least five criteria, including A 1: Adequate evidence for at least three criteria in the category 0: Adequate evidence for no more than two criteria in the category		**Select Rating** 0 ○ 1 ○ 2 ● 3 ○

Category III: Monitoring NGSS Student Progress (lessons and units) *The lesson/unit supports monitoring student progress in all three dimensions of the NGSS as students make sense of phenomena and/or design solutions to problems.*

Lesson and Unit Criteria Lessons and units designed for the NGSS include clear and compelling evidence of the following:	**Specific evidence from materials and reviewers' reasoning**	**Evidence of Quality?**	**Suggestions for improvement**
A. **Monitoring 3D student performances:** Elicits direct, observable evidence of three-dimensional learning; students are using practices with core ideas and crosscutting concepts to make sense of phenomena and/or to design solutions.	Undetermined until the unit is aligned with the NGSS 3-dimensional learning	☒ None ☐ Inadequate ☐ Adequate ☐ Extensive	Align unit with the NGSS
B. **Formative:** Embeds formative assessment processes throughout that evaluate student learning to inform instruction.	Multiple formative assessments are included throughout the unit including homework, reading comprehension, monitoring student progress, and worksheets. No multiple choice assessments are included in the unit.	☐ None ☐ Inadequate ☒ Adequate ☐ Extensive	Develop multiple choice questions for each unit.
C. **Scoring guidance:** Includes aligned rubrics and scoring guidelines that provide guidance for interpreting student performance along the three dimensions to support teachers in (a) planning instruction and (b) providing ongoing feedback to students.	No rubrics or scoring guidelines are available. No keys	☒ None ☐ Inadequate ☐ Adequate ☐ Extensive	Develop rubrics and scoring guidelines for all unit assessments.
D. **Unbiased tasks/items:** Assesses student proficiency using methods, vocabulary, representations, and examples that are accessible and unbiased for all students.	The tasks in this unit seem unbiased, however, they are more suited to accelerated biology students. I believe that academic biology students would have a difficult time with some of the tasks, the vocabulary, and concepts in this unit.	☐ None ☐ Inadequate ☒ Adequate ☐ Extensive	I suggest that the student target audience be stated in the unit introduction, and suggestions for differentiating the unit be made.
Rating for Category III. Monitoring NGSS Student Progress—*lessons* After carefully weighing the evidence, reasoning, and suggestions for improvement, rate the degree to which the lesson met this category. ***If you are evaluating an instructional unit rather than a single lesson, continue on to evaluate criteria E–F and rate Category III overall below.***	***Lesson* Rating scale for Category III (Criteria A–D only):** **3:** At least adequate evidence for all criteria in the category; extensive evidence for at least one criterion **2:** Some evidence for all criteria in the category and adequate evidence for at least three criteria, including A **1:** Adequate evidence for at least two criteria in the category **0:** Adequate evidence for no more than one criterion in the category		**Select Rating** **0** ○ **1** ● **2** ○ **3** ○

Category III: Monitoring NGSS Student Progress (additional criteria *for units only*)
If you are evaluating a lesson, it is not necessary to evaluate criteria E–F. Please enter your rating for a lesson above (after D).

Unit Criteria A unit or longer lesson designed for the NGSS will also include clear and compelling evidence of the following:	**Specific evidence from materials and reviewers' reasoning**	**Evidence of Quality?**	**Suggestions for improvement**
E. **Coherent Assessment system:** Includes pre-, formative, summative, and self-assessment measures that assess three-dimensional learning.	No unit pretest or post-tests are included. No unit summative assessments are included.	☒ None ☐ Inadequate ☐ Adequate ☐ Extensive	Develop unit pre-test and post-test. Develop unit summative assessment
F. **Opportunity to learn**: Provides multiple opportunities for students to demonstrate performance of practices connected with their understanding of disciplinary core ideas and crosscutting concepts and receive feedback	While there are multiple and varied formative assessments in the unit, it is difficult to determine whether the performance of the students would align with the learning opportunities in this unit without the CCC's and DCI's being aligned to the NGSS.	☒ None ☐ Inadequate ☐ Adequate ☐ Extensive	Align the unit with the NGSS
Rating for Category III: Monitoring NGSS Student Progress—*units* After carefully weighing the evidence, reasoning, and suggestions for improvement, rate the degree to which the criteria are met across the unit.	**Unit Rating scale for Category II (Criteria A–G):** 3: At least adequate evidence for all criteria in the category; extensive evidence for at least one criterion 2: Some evidence for all criteria in the category and adequate evidence for at least five criteria, including A 1: Adequate evidence for at least three criteria in the category 0: Adequate evidence for no more than two criteria in the category		**Select Rating** **0 1 2 3** ○ ○ ○ ○

Category Ratings:

Transfer your team's ratings from each category to the following chart and add the scores together for the overall score:

Category ratings			Total Score
Category I: NGSS 3D Design	**Category II: NGSS Instructional Supports**	**Category III: Monitoring NGSS Student Progress**	
0 ○ 1 ● 2 ○ 3 ○	0 ○ 1 ○ 2 ● 3 ○	0 ● 1 ○ 2 ○ 3 ○	3

Overall ratings: The score total is an *approximate* guide for the rating. Reviewers should use the evidence of quality across categories to guide the final rating. In other words, the rating could differ from the total score recommendations if the reviewer has evidence to support this variation.	**E: Example of high quality NGSS design**—High quality design for the NGSS across all three categories of the rubric; a lesson or unit with this rating will still need adjustments for a specific classroom, but the support is there to make this possible; exemplifies most criteria across Categories I, II, & III of the rubric. (total score ~8–9) **E/I: Example of high quality NGSS design if Improved**—Adequate design for the NGSS, but would benefit from some improvement in one or more categories; most criteria have at least adequate evidence (total score ~6–7) **R: Revision needed**—Partially designed for the NGSS, but needs significant revision in one or more categories (total ~3–5) **N: Not ready to review**—Not designed for the NGSS; does not meet criteria (total 0–2)	**Select the overall rating below:** E ○ E/I ○ R ● N ○

APPENDIX G. SELF-STUDY RESEARCH PROJECT TIMELINE

Study Phase	Dated Notes
Phase I BEFORE ENACTMENT	
Author research questions.	Summer 2016 – Included in Chapter 3
Establish my critical friend team.	Fall 2016 - Described in Chapter 3
Observe and videotape classroom dynamics while teaching a traditional biology unit.	Fall 2016 – Will occur at the end of 1st semester during my 8th period accelerated biology class.
Articulate rationale of the study.	Summer 2016 – Chapter 1
Frame research questions.	Summer 2016 – Chapters 1 & 3
Assess research ethics of the study.	Summer 2016 – Chapter 3
Write research proposal.	Spring 2016
Preliminary Exam	Fall 2016
Describe context: community, school, and classroom.	Summer 2016 – Chapter 3
Describe participants.	Summer 2016 – Chapter 3
Propose data sources.	Summer 2016 – Chapter 3
Plan purposeful pedagogies.	Winter 2015: Developed the cell division and genetics unit. (See Appendix C for the unit outline). This unit was dismissed as a model NGSS unit due to content clarity and three-dimensional learning alignment issues. Summer 2016: Professionally developed Project Neuron biology unit Selected: *What makes me tick...tock? Circadian rhythms, genetics, and health ("Project NEURON," 2016)* See Appendix D for unit overview of the curricular unit. A link to the Project Neuron website and the full instructional unit is here: https://neuron.illinois.edu/
Obtain IRB approval	Fall 2016 – See Appendix E
Evaluation of a traditionally taught biology unit using a modified EQuIP Rubric	Fall 2016 – 8th period accelerated biology class.
Phase II DURING ENACTMENT	
Enact study.	Spring 2017

Study Phase	Dated Notes
Observe and videotape classroom dynamics while teaching the Project Neuron Unit	Spring 2017
Evaluation of the Project Neuron unit using a modified EQuIP rubric.	
Describe data sources.	Spring 2017
Explain data analysis.	Spring 2017
Validate with critical friends.	Spring 2017
Phase III AFTER ENACTMENT	
Discussion: Impact on Teacher.	Spring 2017
Discussion: Impact on Education Field.	Spring 2017
Evaluation of data and suggestions for how the Project Neuron unit can be adjusted for better alignment to three-dimensional learning.	Spring 2017
Write study limitations.	Spring 2017
Include references.	Summer 2016, to be updated Spring 2017
Insert appendixes.	Summer 2016, to be updated Spring 2017
Write abstract.	Spring 2017
Complete final project.	Spring 2017
Present & Defend	Spring 2017

APPENDIX H. IRB APPROVAL

IRB EXEMPT APPROVAL
RPI Name: David Brown
Project Title: Using self-study to change a secondary biology teacher's practice
IRB #: 17120

Approval Date: September 16, 2016

Dear Dr. Brown and Mr. Henigman:

Thank you for submitting the completed IRB application form and related materials. Your application was reviewed by the UIUC Office for the Protection of Research Subjects (OPRS). OPRS has determined that the research activities described in this application meet the criteria for exemption at 45CFR46.101(b)(1). This message serves to supply OPRS approval for your IRB application.

Please contact OPRS if you plan to modify your project (change procedures, populations, consent letters, etc.). Otherwise you may conduct the human subjects research as approved for a period of five years. Exempt protocols will be closed and archived at the time of expiration. Researchers will be required to contact our office if the study will continue beyond five years.

Copies of the attached, date-stamped consent and assent form(s) are to be used when obtaining informed consent. We appreciate your conscientious adherence to the requirements of human subjects research. If you have any questions about the IRB process, or if you need assistance at any time, please feel free to contact me at OPRS, or visit our website at http://oprs.research.illinois.edu

Sincerely,

Ronald Banks, MS, CIP
Human Subjects Research Coordinator, Office for the Protection of Research Subjects
Attachments: approved parent consent/assent letters
Ron Banks, MS, CIP
Human Subjects Coordinator
UIUC Office for the Protection of Research Subjects
Suite 203, MC-419
528 E. Green
Champaign, IL 61820
Phone: 217-244-3939
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APPENDIX I. DNA AND CELL DIVISION UBD

From the Champaign Unit #4 School District DNA & Cell Division Unit UbD, 2016.

In the Public Domain.

DNA & Cell Division UbD

BIG IDEA: Cell growth and division is essential for the continuity of life.

STAGE ONE: DESIRED RESULTS
(Next Generation Science Standards)

HS-LS1 From Molecules to Organisms: Structures and Processes
LS1.A: Structure and Function • All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins. HS-LS1-1: Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells. [*Assessment Boundary: Assessment does not include identification of specific cell or tissue types, whole body systems, specific protein structures and functions, or the biochemistry of protein synthesis.*]
LS1.B: Growth and Development of Organisms • In multicellular organisms individual cells grow and then divide via a process called mitosis, thereby allowing the organism to grow. The organism begins as a single cell (fertilized egg) that divides successively to produce many cells, with each parent cell passing identical genetic material (two variants of each chromosome pair) to both daughter cells. Cellular division and differentiation produce and maintain a complex organism, composed of systems of tissues and organs that work together to meet the needs of the whole organism. HS-LS1-4: Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms. [*Assessment Boundary: Assessment does not include specific gene control mechanisms or rote memorization of the steps of mitosis.*]

CROSSCUTTING CONCEPTS
Structure and Function • Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. (HS-LS1-1) Systems and System Models

- Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. (HS-LS1-4)

SCIENCE & ENGINEERING PRACTICES

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-LS1-1)

Developing and Using Models

Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show how relationships among variables between systems and their components in the natural and designed worlds.

- Use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-LS1-4)

ESSENTIAL QUESTIONS

- How do organisms live, grow, respond to their environment, and reproduce?
- How do organisms grow and develop?
- How does the structures of DNA relate to its function in the cell?
- What is the purpose of cell division?
- How are the characteristics of one generation passed to the next?
- How are the characteristics from generation related to the previous generation?
- What is the purpose of meiosis?

ENDURING UNDERSTANDINGS

- DNA is the genetic code for all living organisms.
- The discovery that DNA is the genetic code involved many experiments and controversy.
- The structure of DNA allows it to perform a specific function in the cell.
- Meiosis and mitosis are similar processes with different goals.
- The purpose of meiosis is to reduce chromosome numbers in gametes.
- Genetic mutations can lead to genetic diversity.

CORE KNOWLEDGE

- The DNA molecule is responsible for determining inherited traits.
- DNA replication can result in an accurate copy of the molecule, or mutations can occur.
- The DNA code determines the order of amino acids in the making of proteins.
- The process of sexual reproduction requires the production of gametes through meiosis.
- Meiosis involves a second division that results in a reduction in chromosome number in gametes.
- Gametes are cells with a haploid chromosome number.
- Gamete formation results in the separation of parents' genes for a specific trait.
- Chromosomes carry genetic information from parent to offspring.

ESSENTIAL VOCABULARY

- DNA
- Nucleotide
- Cell cycle
- Eukaryote
- Amino acid
- Chromosome
- Mutation
- Base pair
- Gene
- Interphase
- Mitosis
- Meiosis
- Protein
- Haploid
- Diploid
- RNA
- Enzyme
- Cytokinesis
- Regulation
- Cancer
- Replication (accel)
- Transcription (accel)
- Translation (accel)

SCIENCE PROCESS SKILLS

- Use scientific argumentation within a variety of contexts.
- Awakening and encouraging curiosity about how traits are passed from one generation to another.
- Thinking critically and logically about evidence and explanations.
- Gathering and organizing data into charts and tables.
- Work in teams to complete challenges and experiments.

HABITS OF MIND

Values and Attitudes

- **Honesty** - Honesty is highly prized in the scientific community and essential to the scientific way of thinking and doing. In school there are numerous opportunities to show what honesty means and how it is valued.
- **Curiosity -** By fostering student curiosity, teachers can help students uncover ways to find answers to questions about how the world works.
- **Openness to New Ideas -** New ideas are essential for the growth of science. Science education should help all students understand the great importance of carefully considering ideas that at first may seem troublesome to them or at odds with what they generally believe.

- **Informed Skepticism -** Science is characterized as much by skepticism as by openness. Science education can help students see the social value of systematic skepticism and develop a healthy balance in their own minds between openness and skepticism.

Computation and Estimation - Science literacy includes being able to use computational tools thoughtfully and with confidence. The teaching of science should include problem solving that emerges from student activities and the content being studied. It requires students to make calculations and check their answers against their estimates and their knowledge of the problem.

Manipulation and Observation - Education for science literacy implies that students develop the habit of using tools to solve practical problems and to increase their understanding of how the world works. Tools, from hammers and notebooks to cameras and computers, extend human capabilities.

Critical Response Skills - In various forms, the mass media, teachers, and peers inundate students with assertions, arguments, and claims about all kinds of things. Science education should prepare people to read or listen to such assertions critically, deciding what evidence to pay attention to and what to dismiss. Furthermore, people should be able to apply those same critical skills to their own observations, arguments, and conclusions, thereby becoming less bound by their own prejudices and rationalizations. These critical response skills can be learned, and with practice, can become a lifelong habit of mind. Critical response skills include, but may not be limited to: questioning the reliability of data; questioning sources of information for validity and bias; making sure scientific methods are reliable, consistent and reproducible; recognizing multiple points of view; and recognizing that scientific understanding is a matter of interpretation.

APPLICATIONS OF LEARNING

- Solving Problems - Recognize and investigate problems; formulate and propose solutions supported by reason and evidence.
- Communicating - Express and interpret information and ideas.
- Using Technology - Use appropriate instruments, electronic equipment, computers and networks to access information, process ideas and communicate results.
- Working on Teams - Learn and contribute productively as individuals and as members of groups.
- Making Connections - Recognize and apply connections of important information and ideas within and among learning areas

STAGE TWO: DETERMINE ACCEPTABLE EVIDENCE

FORMATIVE ASSESSMENTS	
Laboratories and Activities	Reflections

• Building a DNA Model • Strawberry DNA Extraction • Cell Division Modeling (pipe cleaners, white boards, clay) • Meiosis Modeling	•

SUMMATIVE ASSESSMENTS	
Performance Tasks	Other Evidence

STAGE THREE: LEARNING PLAN

*** see landscape version for NGSS connections ***

D	Topic/Activity	Materials Needed
1	Historical Perspectives • Watson, Crick, and Franklin • CER for most significant contribution to understanding of DNA structure •	
4 days	Chromosome/DNA Structure • Intro Reading/Coloring—discipline literacy • PPT notes or group activity • DNA Structure POGIL, p. 139-140 (no replication, but add #16 on p. 142) • DNA models—paper, marshmallow, pop-it beads •	Supplies for DNA modeling
1 day	Central Dogma • Big picture of DNA → RNA → Proteins • Overall concept for academic • Possibly replication/transcription/translation for accelerated	

3-4 day	Cell Division • Purpose • Main events (see clarification HS-LS1-4—less focus on rote memorization of phases) PPT or jigsaw/expert groups • Cell cycle POGIL (p. 113-118, teacher resources p. 119) • Mitosis POGIL (p. 121-125, teacher resources p. 126-127) • Onion Root tip lab (in-class or online) • Model Cell Division—pipe cleaners, pop-it beads	
1 days	Mutations • Causes • Results—no change, negative, positive • Change the recipe, change the product	
2-3 days	Cancer • what is it, causes, prevention, treatment • PPT notes/animation • Environmental Interactions on Gene Expression (likelihood to get cancer) • CCSS article	
1 days	Stem Cells and Cell Differentiation • CER, argumentation	
3-4 days	Meiosis • Purpose • Main events (see clarification HS-LS3-2—less focus on rote memorization of phases) • What might go wrong (nondisjunction) • Meiosis POGIL (p.129-136, teacher resources p. 137) ○ Includes gametogenesis and crossing over/genetic variation • Model meiosis and crossing over with pipe cleaners or pop-it beads	
2-3 days	Assessments	

Common Core State Standards Connections:

ELA/Literacy -

RST.11-12.1	Cite Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-LS1-6),(HS-LS2-3)
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-LS1-6),(HS-LS2-3)
WHST.9-12.5	Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience. (HS-LS1-6),(HS-LS2-3)
WHST.9-12.9	Draw evidence from informational texts to support analysis, reflection, and research. (HS-LS1-6)
SL.11-12.5	Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. *(HS-LS1-5),(HS-LS1-7)*
Mathematics -	
MP.2	Reason abstractly and quantitatively. (HS-LS2-4)
MP.4	Model with mathematics. *(HS-LS2-4)*
HSN.Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-LS2-4)
HSN.Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. *(HS-LS2-4)*
HSN.Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-LS2-4)

APPENDIX J. ECOLOGY UNIT UBD

Ecology Unit Understanding by Design (UbD), 2016. Champaign Unit #4 School District

BIG IDEA: *The existence of life on Earth depends on interactions among organisms and between organisms and their environment.*

STAGE ONE: DESIRED RESULTS
(Next Generation Science Standards)

HS-LS1 From Molecules to Organisms: Structures and Processes

LS1.C: Organization for Matter and Energy Flow in Organisms

- The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen.

HS-LS1-5: Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy. [Clarification Statement: Emphasis is on illustrating inputs and outputs of matter and the transfer and transformation of energy in photosynthesis by plants and other photosynthesizing organisms. Examples of models could include diagrams, chemical equations, and conceptual models.] [*Assessment Boundary: Assessment does not include specific biochemical steps.*]

- As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products.

HS-LS1-6: Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules. [Clarification Statement: Emphasis is on using evidence from models and simulations to support explanations.] [*Assessment Boundary: Assessment does not include the details of the specific chemical reactions or identification of macromolecules.*]

HS-LS1-7: Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy. [Clarification Statement: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration.] [*Assessment Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.*]

- As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment.

  HS-LS1-7: Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy. [Clarification Statement: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration.] [*Assessment Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.*]

HS-LS2 Ecosystems: Interactions, Energy, and Dynamics

LS2.A: Interdependent Relationships in Ecosystems

- Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem.

  HS-LS 2-1: Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales. [Clarification Statement: Emphasis is on quantitative analysis and comparison of the relationships among interdependent factors including boundaries, resources, climate, and competition. Examples of mathematical comparisons could include graphs, charts, histograms, and population changes gathered from simulations or historical data sets.] [*Assessment Boundary: Assessment does not include deriving mathematical equations to make comparisons.*]

  HS-LS 2-2: Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. [Clarification Statement: Examples of mathematical representations include finding the average, determining trends, and using graphical comparisons of multiple sets of data.] [*Assessment Boundary: Assessment is limited to data provided.*]

LS2.B: **Cycles of Matter and Energy Transfer in Ecosystems**

- Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.

HS-LS 2-3: Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions. [Clarification Statement: Emphasis is on conceptual understanding of the role of aerobic and anaerobic respiration in different environments.] [*Assessment Boundary: Assessment does not include the specific chemical processes of either aerobic or anaerobic respiration.*]

- Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.

HS-LS 2-4: Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem. [Clarification Statement: Emphasis is on using a mathematical model of stored energy in biomass to describe the transfer of energy from one trophic level to another and that matter and energy are conserved as matter cycles and energy flows through ecosystems. Emphasis is on atoms and molecules such as carbon, oxygen, hydrogen and nitrogen being conserved as they move through an ecosystem.] [*Assessment Boundary: Assessment is limited to proportional reasoning to describe the cycling of matter and flow of energy.*]

- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.

HS-LS 2-5: Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere. [Clarification Statement: Examples of models could include simulations and mathematical models.] [*Assessment Boundary: Assessment does not include the specific chemical steps of photosynthesis and respiration.*]

LS2.C: **Ecosystem Dynamics, Functioning, and Resilience**

- A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any

population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. HS-LS 2-2: Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. [Clarification Statement: Examples of mathematical representations include finding the average, determining trends, and using graphical comparisons of multiple sets of data.] [Assessment Boundary: Assessment is limited to provided data.] HS-LS 2-6: Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. [Clarification Statement: Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and extreme changes, such as volcanic eruption or sea level rise.] • Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. HS-LS 2-7: Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.* [Clarification Statement: Examples of human activities can include urbanization, building dams, and dissemination of invasive species.]
LS2.D: **Social Interactions and Group Behavior** • Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives. HS-LS 2-8: Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce. [Clarification Statement: Emphasis is on: (1) distinguishing between group and individual behavior, (2) identifying evidence supporting the outcomes of group behavior, and (3) developing logical and reasonable arguments based on evidence. Examples of group behaviors could include flocking, schooling, herding, and cooperative behaviors such as hunting, migrating, and swarming.]
HS-LS4: Biological Evolution: Unity and Diversity
LS4.D: **Biodiversity and Humans**

- Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction).
- **Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.**

HS-LS 4-6: Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.* [Clarification Statement: Emphasis is on designing solutions for a proposed problem related to threatened or endangered species, or to genetic variation of organisms for multiple species.]

CROSSCUTTING CONCEPTS

Cause and Effect
- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS 2-8)

Energy and Matter
- Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems. (HS-LS 2-4)
- Energy drives the cycling of matter within and between systems. (HS-LS 2-3)

Stability and Change
- **Much of science deals with constructing explanations of how things change and how they remain stable. (HS-LS 2-6, 2-7)**

Scale, Proportion, and Quantity
- The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. (HS-LS 2-1)
- Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. (HS-LS 2-2)

Systems and System Models
- Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. (HS-LS 2-5)

SCIENCE AND ENGINEERING PRACTICES

Asking Questions and Defining Problems

Asking questions and defining problems in 9-12 builds on K-8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations.
- Ask questions that arise from examining models or a theory to clarify relationships.

Developing and Using Models

Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show how relationships among variables between systems and their components in the natural and designed worlds.

- Develop a model based on evidence to illustrate the relationships between systems or components of a system. (HS-LS2-5)

Planning and Carrying Out Investigations

Planning and carrying out in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.

Using Mathematics and Computational Thinking (not SY13-14)

Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical and/or computational representations of phenomena or design solutions to support explanations. (HS-LS2-1)
- Use mathematical representations of phenomena or design solutions to support and revise explanations. (HS-LS2-2)
- Use mathematical representations of phenomena or design solutions to support claims. (HS-LS2-4)
- Create or revise a simulation of a phenomenon, designed device, process, or system. (HS-LS4-6)

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-LS2-3)
- Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-LS2-7)

Engaging in Argument from Evidence

Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.

- Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. (HS-LS2-6)
- Evaluate the evidence behind currently accepted explanations to determine the merits of arguments. (HS-LS2-8)

Connections to Nature of Science

Scientific Knowledge is Open to Revision in Light of New Evidence

- Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. (HS-LS2-2),(HS-LS2-3)
- Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation. (HS-LS2-6),(HS-LS2-8)

ESSENTIAL QUESTIONS

(adapted from K-12 Framework core ideas)

- How and why do organisms interact with their environment and what are the effects of these interactions?
- How do organisms interact with the living and nonliving environments to obtain matter and energy?
- How do plants, animals, and microbes interact within different habitats?
- How do organisms interact in groups so that the individuals benefit?
- How are ecosystems organized?
- What happens to ecosystems when the environment changes?
- How does energy move through an ecosystem?
- How do organisms get the energy they need to survive?
- Why is the cycling of matter important to life on Earth?
- How does a change in abiotic and/or biotic factors influence the stability or progression of an ecosystem?
- How does human activity affect the environment?
- How do an organism's adaptations (structure, behavior) determine its niche (role) in the environment?

ENDURING UNDERSTANDINGS

(adapted from K-12 Framework grade band endpoints)

- The majority of the Earth's organisms depend on the sun for energy.
- The paths of energy transfer can be followed through food chains, food webs, and trophic levels.
- Organisms have evolved over time to fit within the niche they live.
- Ecosystems are dynamic—stability and resilience are dependent on change in physical environment and shifts in populations.
- Ecosystems have carrying capacities related to resource availability and challenges (predation, competition, disease).

- Ecosystems are sustained by the continuous flow of energy and recycling of matter and nutrients within the system.
- Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.
- Human activity can disrupt an ecosystem and threaten the survival of some species.
- Sustaining biodiversity is essential to supporting and enhancing life on Earth.
- Group behavior has evolved because membership can increase survival for individuals (and genetic relatives).

CORE KNOWLEDGE

(adapted from K-12 Framework grade band endpoints)

- Ecosystems are complex interactive systems that include biotic and abiotic components.
- Ecosystems have carrying capacities that limit the number of organisms (within populations) that they can support.
- Interactions (competition, predation, symbiosis) among organisms influence their growth, survival, and reproduction as a population.
- Most producers harness the sun's energy directly through photosynthesis. (chemosynthesis)
- Consumers use the sun's energy indirectly by eating producers or other consumers.
- Decomposers recycle nutrients back into the environment.
- The amount of energy available to a higher trophic level is directly related to the number of organisms at that level (inefficiency of energy transfer).
- Competition among species is ultimately competition for matter and energy needed to sustain life.
- Disruptions to any abiotic or biotic component of an ecosystem can lead to shifts in its populations.
- Stability in an ecosystem is a balance between competing effects and is affected by alteration of habitats.
- Ecosystems with greater biodiversity tend to be more stable and more resilient to change.
- Changes in biodiversity can influence humans' resources (food, energy) as well as ecosystem "services" (decomposition of wastes, water purification, recycling of nutrients).
- Human activity can have an adverse effect of biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change.
- Animals have a strong drive for social affiliation and will suffer (behaviorally and physiologically) if reared in isolation even if physical needs are met.

ESSENTIAL VOCABULARY

- Abiotic
- Biotic
- Biomagnification
- Food web
- Decomposer
- Niche

• Ecology • Population • Biome • Ecosystem • Predator • Prey • Organism	• Trophic level • Habitat • Competition • Biodiversity • Invasive species • Autotroph • Heterotroph	• Producer • Symbiosis • Adaptation • Consumer (primary, secondary, tertiary)

SCIENCE PROCESS SKILLS

- Compare/ contrast different kingdoms of life
- Interpret or create models and/or illustrations of the cell and the cell membrane
- Use scientific argumentation within a variety of contexts.
- Organize data into graphs and tables
- Obtain accurate measurements.

HABITS OF MIND

it of using tools to solve practical problems and to increase their understanding of how the

ion with fidelity and clarity, and to read and listen with understanding.

APPLICATIONS OF LEARNING

- Solving Problems - Recognize and investigate problems; formulate and propose solutions supported by reason and evidence.
- Communicating - Express and interpret information and ideas.
- Using Technology - Use appropriate instruments, electronic equipment, computers and networks to access information, process ideas and communicate results.
- Working on Teams - Learn and contribute productively as individuals and as members of groups.
- Making Connections - Recognize and apply connections of important information and ideas within and among learning areas

STAGE TWO: DETERMINE ACCEPTABLE EVIDENCE

FORMATIVE ASSESSMENTS	SUMMATIVE ASSESSMENTS
• Biomagnification Articles • Game (Project Neuron) • Read/response articles • Intro to Ecology Vocab Activity • Make observations, group observations: abiotic/biotic etc.	• Ant behavior (bridging gaps, pheromones for tracking food) • Biome in a Bottle • Biomagnification Game Analysis (Project Neuron) • Kaibab Deer Analysis

• Vocabulary Quiz • Oh Deer! Activity • POGIL activities	• End-of-Unit Assessment

Performance Tasks

Daphnia experimental design
• Well-fed Daphnia can lay eggs in 2.8 days
• Predator/prey observations
• Predation rate
  ○ How fast are they eaten
  ○ How big do they need to be before no longer preyed upon?
• Survival vs. reproduction
  ○ Bigger Daphnia make more babies, but are also easier to be preyed up (visibility)
Food web and trophic pyramid activity
• take apart food web and place organisms in the appropriate trophic level
• open response question "what if this organism is removed or new one added?" (LS 2.B)
Biome Project
Biodiversity Beans Activity
biodiversity index (math calc)

STAGE THREE: LEARNING PLAN

Duration	**Topic/Activity**	**Materials Needed**
2 days	Intro to Ecology • go outside and make observations • students work in groups to categorize observations • discuss and re-categorize observations based on biotic and abiotic factors • becomes beginning of notes	
2-3 days	Ecology Vocabulary Pretest Begin Vocab Activity • students work in groups to sort and match vocabulary words and definitions • teacher monitors for accuracy—groups continue to work until all are paired correctly • groups glue correct pairs onto construction paper or butcher paper; add examples • each student creates a mini-poster to add to their notebook/binder	• Vocabulary words and definitions cut apart and in envelopes • Construction paper or butcher paper • Glue sticks or tape

1 day for set-up	Set up "Biome in a Bottle" • Students will monitor the aquatic ecosystem for 4-5 weeks—collecting data on the biotic and abiotic factors of the ecosystem • Read/respond to Coral Reef article from accessexcellence.com	• Clean (no soap) plastic containers • Distilled water • Aquarium rock • Elodea plants • Pond snails • Pollutants (to imitate fertilizer runoff, garbage runoff, etc) Artificial sunlight for interior classrooms
1 day	"Oh Deer!" population simulation Simulates change in population due to change in resource availability	
3-4 days	What is a population and how do they change? • PPT notes, group discussion, etc based on the previous days' "Oh Deer!" game • Growth/decline, stability, limiting factors, carrying capacity • Exit Slip: population of willow trees (FA) Population Growth POGIL • P. 227-232 (teacher resources p. 233-234) Population Distribution POGIL • P. 221-225 (teacher resources p. 226)	
1 day	Kaibab Deer lesson • Students read about the Kaibab deer population in Arizona and how human impact affected the population • Students will use real-life data to analyze cause and effect	
2 days	What is biodiversity and why is it important? • Ed Portal Video Lesson with Quiz (printed transcript to follow) • Biodiversity with beans?	Link to video: http://education-portal.com/academy/lesson/what-is-biodiversity-definition-and-relation-to-ecosystem-stability.html#lesson

5-6 days	Relationships in an Ecosystem
	• Feeding Relationships
	  ○ Predator-prey, competition (inter and intra)
	• Symbiotic Relationships
	  ○ Mutualism, commensalism, parasitism
	  ○ Ed Portal resources
	• Within populations
	  ○ Ant video clip
	  ○ Ant lab? Feeding habits and communication to colony
	Ecological Relationships POGIL
	• P. 179-186 (teacher resources p. 187)
		Ant Lab: multiple ant colonies, trays, flu on, feeding tubes, plaster of paris/dental stone, sugar conc.

2-3 days	Intro to Food Chains/Webs (SA) • Groups are given cards with organisms and diets and create a food web (specific to ecosystems) • Ed Portal video clip and reading	Link to video: http://education-portal.com/academy/lesson/food-chains-trophic-levels-and-energy-flow-in-an-ecosystem.html#lesson
5-6 days	Trophic Levels and Energy Flow • Origination of energy • Photosynthesis and cellular respiration (conceptual/products and reactants without chemical process and steps) • What's in a Leaf? POGIL Photosynthesis & Respiration POGIL • P. 105-110 (teacher resources p. 111-112) (includes carbon cycle) • Cycling of nutrients (carbon and nitrogen cycles?) Cellular Respiration POGIL for Accel Biology • P. 97-102 (teacher resources p. 103-104) Nutrient Cycle POGIL • P. 171-177 (teacher resources p. 178) Ecological Pyramids POGIL • P. 205-210 (teacher resources p. 211-212) Energy Transfer in Living Organisms POGIL P. 197-201 (teacher resources p. 202-203)	

3-4 days	Toxin Flow through Food Webs
	• Article readings
	    o PBCs in Great Lakes
	    o Gulf Dead Zone
	    o Changing Hudson Project (Cary Institute) with questions
	    o Mercury Poisoning article and activity
	    o Cat-Dancing Disease (Project Neuron)
	    o Nuclear Tuna reading (Project Neuron)
	• Biomagnification Game (Project Neuron)
		Biome game: game board, game pieces/chips/beans, dice, cups with fish labels,

4-5 days	Impact of Introduced/Exotic Species • Intentional and accidental • "The Great Lakes Invasion" from Sea Grant (in part or whole, but especially p. 5 "Why Are Exotics a Problem?" along with specific examples from following pages) • Find local examples— • IDNR research project?	Feral Hogs link to you tube videos from IDNR http://www.dnr.illinois.gov/OI/Pages/BAFeralHogsinIllinois.aspx http://www.youtube.com/MSSTATEwfaTV

5-6 days	Biomes
	• Biomes of North America POGIL (p. 189-194, teacher resources p/195-196)
	• Biome Research Project or Jigsaw
	    o Expert groups and gallery walk
	    o Required information: animal, plant, microbe life; examples of symbiotic relationships, climate, locations/map, human impact, identify producers, consumers, decomposers and their interactions, create a food web, number of organisms at each level (IDNR)—groups divide tasks for some individual accountability to the group product
	• Predict impact of an introduced species, natural disaster, or extinction of particular species (could be part of written assessment)	

2-4 days	Checkpoint Quizzes Mid and End of Unit Assessments	

- Science daily articles such as: fungal infections killing frog populations, white nose fungus in bats, honeybee populations
- BPA-free products—why? Lesson 7 from project neuron
- Bring Back the Wooly Mammoth CER
  45-55 days

Common Core State Standards Connections:

ELA/Literacy -	
RST.9-10.8	Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. (HS-LS2-6),*(HS-LS2-7)*,*(HS-LS2-8)*
RST.11-2.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. *(HS-LS2-1)*,*(HS-LS2-2)*,(HS-LS2-3),(HS-LS2-6),(HS-LS2-8)
RST.11-12.7	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. *(HS-LS2-6)*,*(HS-LS2-7)*,*(HS-LS2-8)*
RST.11-12.8	Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-LS2-6),(HS-LS2-7),(HS-LS2-8)
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. *(HS-LS2-1)*,*(HS-LS2-2)*,(HS-LS2-3)
WHST.9-12.5	Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience. (HS-LS2-3)
WHST.9-12.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-LS2-7)
Mathematics -	
MP.2	Reason abstractly and quantitatively. (HS-LS2-1),(HS-LS2-2),(HS-LS2-4),(HS-LS2-6),*(HS-LS2-7)*
MP.4	Model with mathematics. *(HS-LS2-1)*,*(HS-LS2-2)*,*(HS-LS2-4)*
HSN.Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas;

	choose and interpret the scale and the origin in graphs and data displays. (HS-LS2-1),(HS-LS2-2),(HS-LS2-4),*(HS-LS2-7)*
HSN.Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. *(HS-LS2-1),(HS-LS2-2),(HS-LS2-4),(HS-LS2-7)*
HSN.Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-LS2-1),(HS-LS2-2),(HS-LS2-4),*(HS-LS2-7)*
HSS-D.A.1	Represent data with plots on the real number line. *(HS-LS2-6)*
HSS-C.A.1	Understand statistics as a process for making inferences about population parameters based on a random sample from that population. *(HS-LS2-6)*
HSS-IC.B.6	Evaluate reports based on data. (HS-LS2-6)

APPENDIX K. ECOLOGY PART II EQUIP RUBRIC UNIT ASSESSMENT

EQuIP Rubric for Lessons & Units: Science (Version 3.0)

Reviewer Name or ID: D. Henigman **Grade:** 09 **Lesson/Unit Title:** Ecology Unit Part 2

Category I: NGSS 3D Design (lessons and units): *The lesson/unit is designed so students make sense of phenomena and/or design solutions to problems by engaging in student performances that integrate the three dimensions of the NGSS.*

<table>
<tr>
<th>Lesson and Unit Criteria
Lessons and units designed for the NGSS include clear and compelling evidence of the following:</th>
<th colspan="2">Specific evidence from materials
(what happened/where did it happen)
and reviewer's reasoning
(how/why is this evidence)</th>
<th>Evidence of Quality?</th>
<th>Suggestions for improvement</th>
</tr>
<tr>
<td>A. Explaining Phenomena/Designing Solutions: Making sense of phenomena and/or designing solutions to a problem drive student learning.
i. Student questions and prior experiences related to the phenomenon or problem motivate sense-making and/or problem solving.
ii. The focus of the lesson is to support students in making sense of phenomena and/or designing solutions to problems.
iii. When engineering is a learning focus, it is integrated with developing disciplinary core ideas from physical, life, and/or earth and space sciences.</td>
<td colspan="2">There is no real-life guiding problem or phenomena that drives student learning in the ecology part 2 unit. This unit is predominately teacher driven and not student driven. The Students passively receive knowledge directed by the teacher. The owl pellet dissection lab, the photosynthesis & respiration molecular modeling lab, and the properties of water lab are "cookie cutter" labs that confirm what the teacher has taught, and subsequently do not allow students to modify their understanding of a guiding problem or phenomena.</td>
<td>☐ None
■ Inadequate
☐ Adequate
☐ Extensive</td>
<td>Revise the unit to include a guiding problem or phenomena that drives the unit. Suggestions includes owl predator prey interactions and their niche in the ecosystem tied into the owl pellet dissection.</td>
</tr>
<tr>
<td rowspan="4">B. Three Dimensions: Builds understanding of multiple grade-appropriate elements of the science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCCs) that are deliberately selected to aid student sense-making of phenomena and/or designing of solutions.

i. Provides opportunities to develop and use specific elements of the SEP(s).

ii. Provides opportunities to develop and use specific elements of the DCI(s).

iii. Provides opportunities to develop and use specific elements of the CCC(s).

Evidence needs to be at the element level of the dimensions (see rubric introduction for a description of what is meant by "element")</td>
<td>Document evidence and reasoning, and evaluate whether or not there is sufficient evidence of quality for each dimension separately</td>
<td>Evidence of Quality?</td>
<td rowspan="4">☐ None
■ Inadequate
☐ Adequate
☐ Extensive

(All 3 dimensions must be rated at least "adequate" to mark "adequate" overall)</td>
<td rowspan="4">While the ecology 2 unit does cover the required content, and it did allow for the use of several of the CCC's, the deficit in this unit is in the underdevelopment of the the SEP's. The unit should be examined closely and revised in order to provide for three dimensional learning. Having a a guiding unit problem or phenomena would provide a unit framework to better achieve 3D learning.</td>
</tr>
<tr>
<td>i.
The SP's of asking questions and developing and using models were used in this unit, but not in the context that is intended in the NGSS. Students did construct actual models, but there was not an opportunity for them to come up with an initial model and then modify it during the course of the unit.</td>
<td>☐ None
■ Inadequate
☐ Adequate
☐ Extensive</td>
</tr>
<tr>
<td>ii.
LS1.A, and LS2.A, B, & C were covered in this unit.</td>
<td>☐ None
☐ Inadequate
■ Adequate
☐ Extensive</td>
</tr>
<tr>
<td>iii.
Patterns, Cause & effect, Systems & system models were CCC's used in this unit.</td>
<td>☐ None
☐ Inadequate
■ Adequate
☐ Extensive</td>
</tr>
</table>

C. **Integrating the Three Dimensions:** Student sense-making of phenomena and/or designing of solutions requires student performances that integrate elements of the SEPs, CCCs, and DCIs.	As mentioned above, 3D learning can only be accomplished through the interlacing of SEP's, CCC's, and DCI's. This unit falls short in its teacher centered design and lack of a guiding problem or phenomena. However, solid ecological content was introduced and several of the science practices (although inadequately) were used in the unit.	☐ None ■ Inadequate ☐ Adequate ☐ Extensive	Meet with the biology PLC to redesign the unit. Find an NGSS high quality unit that has an extensive 3D learning design, and scrap this unit.
Rating for Category I. NGSS 3D Design—*lessons* After carefully weighing the evidence, reasoning, and suggestions for improvement, rate the degree to which there is enough evidence to support a claim that the lesson meets these criteria. ***If you are evaluating an instructional unit rather than a single lesson, continue on to evaluate criteria D-F and rate Category I overall below.***	***Lesson* Rating scale for Category I (Criteria A–C only):** **3**: Extensive evidence to meet at least two criteria (and at least adequate evidence for the third) **2**: Adequate evidence to meet all three criteria in the category **1**: Adequate evidence to meet at least one criterion in the category, but insufficient evidence for at least one other criterion **0**: Inadequate (or no) evidence to meet any of the criteria in the category		**Select Rating** **0 1 2 3** ○ ⊙ ○ ○ After rating the lesson, read below for next steps

<u>What's next if the lesson rating is less than a 2?</u>

*If the rubric is being used to approve or vet resources and the lesson or unit does not score at least a "2" in **Category I: NGSS 3D Designed**, the review should stop and feedback should be provided to the lesson developer(s) to guide revisions. If the rubric is being used locally for revising and building lessons, professional judgment should guide whether to continue reviewing the lesson. Categories II and III may be time consuming to evaluate if Category I has not been met and the feedback may not be useful if significant revisions are needed in Category I, but evaluating these criteria in a group may support deeper and more common understanding of the criteria in these categories and more complete feedback to the lesson developer (if they are not in the room) so that Categories II and III are more likely to be met with fewer cycles of revision.*

<u>What's next if the lesson rating is a 2 or 3?</u>

If you are evaluating a lesson that shows sufficient evidence of quality to warrant a rating of either a 2 or a 3 for Category I, proceed to Category II: NGSS Instructional Supports

Category Ratings:

Transfer your team's ratings from each category to the following chart and add the scores together for the overall score:

Category ratings			
Category I: NGSS 3D Design	**Category II: NGSS Instructional Supports**	**Category III: Monitoring NGSS Student Progress**	**Total Score**
0 1 2 3 (1 selected)	0 1 2 3 (0 selected)	0 1 2 3 (0 selected)	1

Overall ratings:		**Select the overall rating below:**
The score total is an *approximate* guide for the rating. Reviewers should use the evidence of quality across categories to guide the final rating. In other words, the rating could differ from the total score recommendations if the reviewer has evidence to support this variation.	**E: Example of high quality NGSS design**—High quality design for the NGSS across all three categories of the rubric; a lesson or unit with this rating will still need adjustments for a specific classroom, but the support is there to make this possible; exemplifies most criteria across Categories I, II, & III of the rubric. (total score ~8–9) **E/I: Example of high quality NGSS design if Improved**—Adequate design for the NGSS, but would benefit from some improvement in one or more categories; most criteria have at least adequate evidence (total score ~6–7) **R: Revision needed**—Partially designed for the NGSS, but needs significant revision in one or more categories (total ~3–5) **N: Not ready to review**—Not designed for the NGSS; does not meet criteria (total 0–2)	**E** **E/I** **R** **N** (N selected)

Overall Summary Comments:

APPENDIX L. PHASE I INITIAL CODING TABLE

Phase I – Initial Coding Table		
Darin	Joan	Angela
NGSS integration	Use both model and phenomenon	Storyline for whole year
Phenomenon based instruction	Phenomenon helps explain the model	Phenomena integration
Unit storyline	Change current practice	Physical science background understanding
Storyline unit	Modify labs make more investigative	Memorization versus understanding
Model versus phenomenon	Students design labs & direct learning	Models plus phenomena needed for understanding
Physical science model preference	NGSS student centered	Combination of models and phenomena
Model developed through unit	Implementation time concerns	Phenomena based curriculum
Topic sequence for better understanding	Course length NGSS time concerns	Phenomenon becomes the model
What is 3D learning?	Two versus three year model	Rote memorization versus understanding
Develop and modify models and phenomena	State should provide NGSS curriculum	Lack of unit phenomenon in traditional teaching
Traditional teaching verify facts	Adoption concerns what's out there?	Parts of unit with phenomenon
Two year model surface teaching	Will new curriculum meet NGSS needs?	Teacher adjusts role
Most students learn science traditionally	Skeptical we will be provided NGSS curriculum	Student mistakes in learning okay
Teacher versus state role in curriculum development	NGSS trained teachers protect curriculum	NGSS takes longer to teach correctly
Teachers not curriculum developers		NGSS standards make sense

Phase I – Initial Coding Table		
Darin	Joan	Angela
Teachers as curriculum designers concerns Teacher understanding of the NGSS Science practices versus rote memorization Intentions of NGSS designers Learning science practices versus rote knowledge Figuring out problems versus confirming knowledge 3D learning takes more time Students should understand PE's Higher Ed wants students to think like scientists Facts are available at students' fingertips NGSS compared to working in a job Problem solving most important part of learning NGSS limits what is traditionally learned Identifying phenomenon	Most teachers not trained NGSS understanding relies on professional development Three year model allows for better 3D learning Two year model skims the surface 3D learning must have a common storyline Importance of professional development Integrate 3D learning slowly Begin with one of each 3 dimensions at first Questioning phenomenon in traditional lab Storyline is more involved Using owls as a unit model	Achieving NGSS standards not possible in 2/3 year plan Phenomena/model based not the only way Lack of teacher investment in NGSS design Some students successful being taught traditionally Benefits of 3D learning Benefits of both traditional and 3D learning together Professional development limited but useful Student failure linked to teacher understanding of NGSS Students not getting big picture under NGSS 3D learning provides Ah Ha moments Students can solve problems but don't know facts How do you know when 3D learning is happening? 3D teaching versus 3D learning Students learn to become critical thinkers on their own

Phase I – Initial Coding Table		
Darin	Joan	Angela
3D Learning	Student Understanding & Learning	Phenomenon/Model Based Learning/Storyline
NGSS Curriculum Tensions	NGSS Implementation Tensions	Teacher Training & Understanding NGSS

APPENDIX M. WHAT MAKES ME TICK…TOCK SUMMATIVE EXAM

Name ____________________ **Period 1 2 3 4 5 6 7 8**

Accelerated Biology – What Makes Me Tick…Tock? Unit Exam

Part I – Multiple Choice – Select the best answer to the questions below.

1. ___ When an organism is synchronized to the day/night cycle created by the sun, this is known as:
   a. free running c. a phase shift
   b. entrainment d. a lesion
2. ___ Fruit flies have circadian rhythms which match their bodies inner, endogenous rhythms. What is called?
   a. free running c. a phase shift
   b. entrainment d. a lesion
3. ___ When the activity of an animal is either naturally or artificially moved up or back a few hours, this results in a(n):
   a. circadian rhythm c. phase shift
   b. entrainment d. lesion
4. ___ You keep waking up at the same time each morning without using an alarm clock. This is due to:
   a. being crepuscular c. a phase shift
   b. your endogenous inner rhythms d. a lesion
5. ___ An environmental agent or event that provides the stimulus setting or resetting of an organisms' biological clock is:
   a. caused by a phase shift c. being entrained
   b. caused by a lesion d. a zeitgeber
6. ___ What is it called when part of an organisms' brain that controls circadian rhythms is damaged?
   a. a zeitgeber c. a lesion
   b. an entrainment d. a phase shift
7. ___ Biological activity that occurs in approximately 24 hour periods or cycles are:
   a. circadian rhythms c. caused by a phase shift mutation
   b. due to free running d. caused by lesions

Part II – True/False (write A or true, or B for false)

8. ___ Organisms that are crepuscular are active mostly during the day.
9. ___ Organisms classified as hummingbirds are ready for action mostly during the night.
10. ___ Nocturnal animals usually feed during the day.
11. ___ Diurnal animals are active at dusk and dawn.
12. ___ Larks are most productive in late morning.
13. ___ Owls are most active around 5:30 pm.

14. ___ Hummingbirds are ready for action both early in the morning and late at night.
15. ___ Damage to part of the brain that controls circadian rhythms is known as a lesion.

Part III – Experimental Design. Use your knowledge of circadian rhythms to design a sleep related experiment.

What is the problem?

What is your hypothesis?

What type of data will you collect? Qualitative or quantitative? Describe your data collection in detail.

What is the control group? ____

What is the experimental group? ____

What is the dependent variable? ____

What is the independent variable? ____

Draw or describe the experimental design in detail using all relevant biological terminology related to circadian rhythms:

Part IV – DNA and Mutation Model

Using your knowledge about the structure of DNA, neatly and accurately draw and label a DNA molecule and include all the components that we discussed in class. Also, describe what a mutation is, and use your model to illustrate the "per" mutation.

Part V – Sleep Study Analysis and School Day Starting Time Proposal (CER)

Make a claim as to what time you think the school day should start. Using the data that you collected during your sleep study, and any other evidence that you learned during the *What makes me tick…tock?* unit, defend the reasoning for your claim.

Claim:

Evidence (state the evidence that supports your claim):

Reasoning (defend your claim using evidence):

APPENDIX N. PHASE II INITIAL CODING TABLE

Phase II – Initial Coding Table		
Darin	Joan	Angela
PE's set	PE's purpose	PE's flexible
PE's restrictive and narrow	Model curriculum	PE's differentiate
PE's unclear	Model curriculum model use	Model curriculum assessment
Model curriculum use	PE's assessment role	PE's restrictive
PE's purpose	Model curriculum assessment	Curriculum alignment tensions
PE's assessment role	Model curriculum characteristics	Curriculum alignment timeline/pilot
Model curriculum assessment	Model curriculum 3D learning	Model curriculum characteristics
Model curriculum 3D learning	Model curriculum assessment	
Curriculum alignment evaluation (EQuIP)	Curriculum alignment differentiation	
Curriculum alignment timeline/pilot	Curriculum alignment tensions	
Model curriculum characteristics	Curriculum alignment timeline	
Code Key		
Model Curriculum Aspects	Performance Expectations Tensions	Curriculum Alignment Tensions

APPENDIX O. WHAT MAKES ME TICK…TOCK SLEEP STUDY

Sleepiness Scale Data Collection Assignment (Summative)

For the next two weeks, you will be collecting detailed data on your sleepiness on Mondays, Thursdays, and Saturdays.

Additionally, you will collect sleepiness data on one of your family members during the same time.

Keep a detailed log of your sleepiness separate and record the following aspects of your sleepiness over the two-week time:

- Waketime
- Bedtime
- Total sleep
- Number of awake hours
- Quality of sleep
- Number of caffeinated drinks
- Other things that may have had an effect on your sleepiness (stress, gaming, etc..)

At the end of the two-week period when you have collected six days of data on both you and your family member, fill out a sleepiness scale graph. The graph should be separate for both you and your family member. Please make sure your graph is:

- Be neat – make your lines straight with a ruler!
- Each day should be a separate color
- Have a key that identifies each day by color

At the end of the two weeks, you will turn in a typed record of your data and both sleepiness scales for a summative assignment grade.

Sleepiness Scale Data Collection Assignment Rubric

Category	4 Exemplary	3 Accomplished	2 Developing	1 Beginning
Requirements	The requirements are met and are exceeded	The requirements are met	Most requirements are met	More than one requirement was not met
Detailed log	A detailed log was kept that went into exquisite details	A detailed log was kept that went into good details	A detailed log was kept that went had missing details	A log was kept that had many missing details
Graphing	A six-day graph was made for each participant with exquisite details	A six-day graph was made for each participant with good details	A six-day graph was made for each participant with missing details	A six-day graph was made, but was missing a participant or data
Assignment neatness and accuracy	The assignment was extraordinarily neat and accurate	The assignment was neat and accurate	The assignment was somewhat messy and inaccurate	The assignment was very messy and inaccurate

APPENDIX P. WHAT MAKES ME TICK…TOCK PRETEST AND POSTTEST

What makes me tick…tock? Unit Pretest

Name____________________

Period: 1 2 3 4 5 6 7 8

1. You've been chosen by NASA to be part of the first manned mission to Saturn. Your team will be spending one year establishing a colony on Saturn. It only takes 11 hours for Saturn to make a full rotation, as compared to Earth's 24-hour day.
   Draw a model of what you think your sleep/wake cycles will be like during your yearlong mission to Saturn. Be sure to describe your model in detail using complete sentences.

2. During your mission to Saturn, you find that the planet has an average temperature of minus 288 degrees Fahrenheit. The heaters in the base struggle to warm the interior, and the crew is constantly trying to keep warm. Predict how do you think these cold temperatures will affect your sleep/wake cycle?

3. You have been exposed to a burst of gamma radiation during your mission to Saturn and your DNA has been damaged. Draw a model of your DNA which shows the damage that has been done to your DNA. Hypothesize how you think that damaged DNA will affect your sleep/wake cycle.

4. A massive storm has blocked out all the sunlight on Saturn for two months during your mission. To conserve power, you are only allowed one hour of artificial light each day. The rest of the time you spend in complete darkness. Predict how you think this reduction in light will impact your sleep/wake cycle.

What makes me tick…tock? Unit Posttest Name ________________________

Period: 1 2 3 4 5 6 7 8

1. You've been chosen by the National Underwater Marine Agency (NUMA) to be a crew member on a state of the art deep sea submarine to investigate the Pacific Ocean's Mariana Trench. Only two other people have descended to the deepest point of the face of the Earth until now. Your team will be spending six months in the nuclear-powered submarine that will operate in the totally dark environment.

Draw a model of what you think your sleep/wake cycles will be like during the six-month long mission to the deepest point on Earth. Make sure you describe your model in detail using complete sentences.

2. During your mission to the Mariana Trench, you find that the water temperature ranges from 34-39 degrees F (1-4 degrees C) outside of the submarine. The heaters inside the nuclear-powered submarine regularly malfunction causing the internal temperatures to average between 80-90 degrees F (27-32 degrees C), and you are uncomfortably warm. Predict how you think these warm temperatures will affect your sleep/wake cycle?

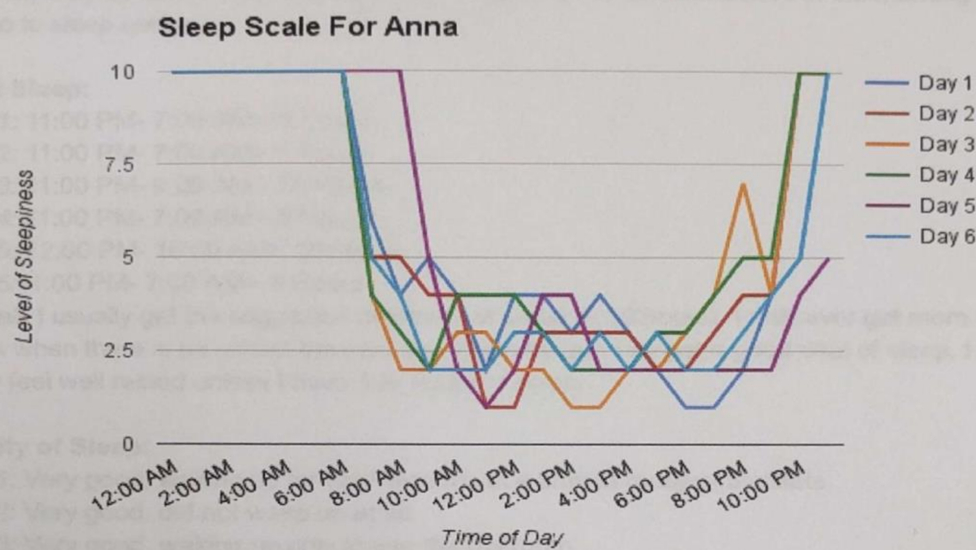
3. You have been exposed to a burst of radiation from the nuclear reactor in the submarine during your submarine, and your DNA has been damaged. Draw a model that shows the damage that has been done to your DNA. Hypothesize how you think the damage to your DNA will affect your sleep/wake cycle.

4. The massive underwater earthquake that damaged the nuclear reactor has also stranded your submarine in the Mariana Trench. To conserve power while you await rescue, all internal lights must be kept off, and you and your crew members are forced to live in complete darkness. Predict how you think that living in complete darkness will impact your sleep/wake cycle.

APPENDIX Q. SLEEP STUDY SUMMATIVE ASSESSMENT STUDENT WORK

Sleepiness Scale Data Collection Assignment

[redacted]



Wake Time/ Number of Awake Hours:

Day 1: From 7:00 AM-11:00 PM>16 Hours
Day 2: From 7:00 AM-11:00 PM>16 Hours
Day 3: From 9:00 AM-11:00 PM>14 Hours
Day 4: From 7:00 AM-11:00 PM>16 Hours
Day 5: From 10:00 AM-12:00 AM>14 Hours
Day 6: From 7:00 AM-11:00 PM>16 Hours
Overall: Almost everyday I was awake for 16 hours, except for one Saturday when I woke up later than usual, and another day which we had off of school.

Bedtime:

Day 1: 11:00 PM- This bedtime could contribute to why I have trouble getting up in the morning.
Day 2: 11:00 PM- This bedtime was early for a Saturday, but I needed to get as much sleep as possible since I had to play volleyball early the next morning.
Day 3: 11:00 PM-This bedtime could contribute to why I have trouble staying awake during school.
Day 4: 11:00 PM- This bedtime could contribute to why I feel like I need coffee in the morning.
Day 5: 12:00 AM- This bedtime is generally how late I stay up on Saturday because I have Church in the morning.
Day 6: 11:00 PM- This bedtime could contribute to why I often oversleep and have to rush getting ready in the mornings.

Overall: I generally fall asleep at 11 on the weekdays and later on the weekends. Often times I'm not exhausted when I go to bed because I am definitely more of a night time person, but I feel like if I am going to wake up early for school, then I need as much sleep as possible. I could probably stay up until 1 in the morning every night, but my responsibilities in the morning make me go to sleep earlier.

Total Sleep:
Day 1: 11:00 PM- 7:00 AM> 8 Hours
Day 2: 11:00 PM- 7:00 AM> 8 Hours
Day 3: 11:00 PM- 9:00 AM> 10 Hours
Day 4: 11:00 PM- 7:00 AM> 8 Hours
Day 5: 12:00 PM- 10:00 AM> 10 Hours
*Day 6:*11:00 PM- 7:00 AM> 8 Hours
Overall: I usually get the suggested allotment of sleep (8-10 hours). I only ever get more than 8 hours when there is no school the next day. Even though I do get a good deal of sleep, I don't really feel well rested unless I have 10+ hours of sleep.

Quality of Sleep:
Day 1: Very good, waking up for only seconds at a time to readjust blankets
Day 2: Very good, did not wake up at all
Day 3: Very good, waking up only to use the restroom
Day 4: Very good, waking up because I was cold, and needed more blankets
Day 5: Very good, it took a little longer to fall asleep than normal, but once I was asleep I didn't wake up again
Day 6: Very good, did not wake up at all
Overall: I generally sleep like a rock once I do fall asleep. My blankets tend to fall off of my bed, so I wake up for maybe 10 seconds to put them back on my bed, but I fall asleep right afterward. I have never really had a problem with poor sleep.

Caffeinated Drinks:
Day 1: 1 soda at 6:00 PM- Did not affect my sleep
Day 2: 1 soda at 6:00 PM- Did not affect my sleep
Day 3: No caffeine
Day 4: 1 soda at 6:00 PM- Did not affect my sleep
Day 5: 2 sodas at 6:00 PM- Did not affect my sleep
Day 6: No caffeine
Overall: Caffeine has never affected my quality/quantity of sleep. I can fall asleep directly after I drink caffeine. I don't usually drink coffee unless I didn't fall asleep at my normal time. Even then, it doesn't actually help me stay awake, it's more of a placebo for me.

Other Factors:
I am usually on my phone for a few minutes before I go to bed, but it doesn't normally cause me to not be able to fall asleep. I take a shower before I go to bed every night, and I think that calms

me down and makes me tired. I also listen to music to help me fall asleep, and the nights that I don't listen to music I can't fall asleep as easily.