Using Storylines to Enhance Student Understanding of Space Systems

By Ron Ruckman

M.S., University of Wyoming, 2018

Plan B Project
Submitted in partial fulfillment of the requirements
for the degree of Masters in Science in Natural Science
in the Science and Mathematics Teaching Center
at the University of Wyoming, 2018

Laramie, Wyoming

Masters' Committee:
Ana Houseal, Associate Professor, Chair
Alan Buss, Associate Professor
Hannah Jang-Condell, Associate Professor
Debbie French, Assistant Professor

Abstract

After the National Research Council's publication of *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* and the subsequent adoption of the *Next Generation Science Standards* (NGSS), teachers were left with a significant challenge. The sheer magnitude of the task of finding, adapting, and creating new curriculum to support the three-dimensional (3D) approach called for in the NGSS was daunting at best. This project was an intentional effort to document the creation process of a 3D NGSS unit by a working teacher. The project used an anchoring storyline as outlined at nextgenstorylines.org. This effort effectively incorporated the Disciplinary Core Ideas (DCIs), the Science and Engineering Practices (SEPs), and the Crosscutting Concepts (CCCs) of the NGSS into an Earth and Space Science unit for eighth grade students. The unit used anchoring phenomena and followed a dynamic science storyline. The vision was to allow students to move into the role of scientists and to allow the teacher to act as a partner in their journey to understanding. In this way, students were able to tap into their innate sense of curiosity which allowed them to drive their own understanding of the big ideas of Earth and Space Science. The process of designing the unit and its subsequent classroom pilot was documented and reviewed. The benefits of using this method, for the teacher and the students, are discussed.

Acknowledgements

I would like to thank my committee members for their support in this endeavor. I would especially like to thank my committee chair, Ana Houseal, for her never-ending commitment to this project and my growth as a teacher. Thank you to my family for putting up with the long hours I spent away from them while I worked on this project. Thank you to my class members for all their help and suggestions along the way. Thank you to my fellow science teacher, Retta Hudlow, for her support and willingness to participate in this project.

Table of Contents

Chapter 1: Introduction

Background

Although attempts had been made to revamp science education before the 1950s, it was the Soviet Union's launch of Sputnik in 1957 that acted as a catalyst to move the country toward true education reform. In 1958 Congress passed, and President Eisenhower signed into law, the National Defense Education Act (NDEA). This law was in direct response to the perception that America was falling behind in technological advancement and it provided funding for schools to improve their curricula. It was intended to bolster the education system to meet national security needs mainly in the areas of science and technology (Hunt, 2016).

However in the late 1960s, as the United States pulled ahead of the Soviet Union in the space race, the nation began to lose interest once again. In the 1970s the public seemed apathetic about education. It was not until Secretary of Education, Terrel H. Bell, appointed the National Commission of Excellence in Education in 1981 that the nation received the wake-up call it needed. The commission was tasked with closely examining the quality of education in the United States. They issued a report called *A Nation at Risk* (National Commission on Excellence in Education, 1983), which revealed what the commission referred to as a crisis in American education. This created a renewed reform effort that initiated the development of new education standards across the country (Ravitch, 1990).

In the late 1980s, the American Association for the Advancement of Science [AAAS] published *Science for All Americans* (AAAS, 1989), which, in turn, lead to their publication of *Benchmarks for Science Literacy* (AAAS, 1993). The association hoped these standards would be used by state and local governments to develop curricula which would give all students the opportunity to reach a high level of achievement. The National Research Council [NRC] added to this effort by publishing The *National Science Education Standards* (NRC, 1996). These standards shifted the focus of science instruction to an emphasis on science literacy and learning through inquiry (NRC, 1996).

Nearly two decades after The National Science Standards were released, the NRC published *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012), hereafter referred to as *the Framework*. The authors of the report took guidance from research on teaching and learning from the prior decades and built on *Science for All Americans* (AAAS, 1989), *Benchmarks for Science Literacy* (AAAS, 1993), and the *National Science Education Standards* (NRC, 1996). The Framework emphasized three dimensions of science education including disciplinary core ideas (DCIs) in the content areas of physical, life and earth sciences, eight science and engineering practices (SEPs), and seven crosscutting scientific concepts (CCCs) (NRC 2012).

In 2013, the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) were finalized and published. These standards were based closely on the Framework. They embraced the three-dimensional theme by incorporating the disciplinary core ideas, science and engineering practices, and crosscutting concepts into each area of science. In Figure 1, Houseal (2015) defines each of these three dimensions and shows how they overlap to give a complete picture of NGSS performance expectations (PEs). It is imperative for teachers to consider how these three dimensions and the nature of science can be integrated in order to achieve the goals of the Framework.

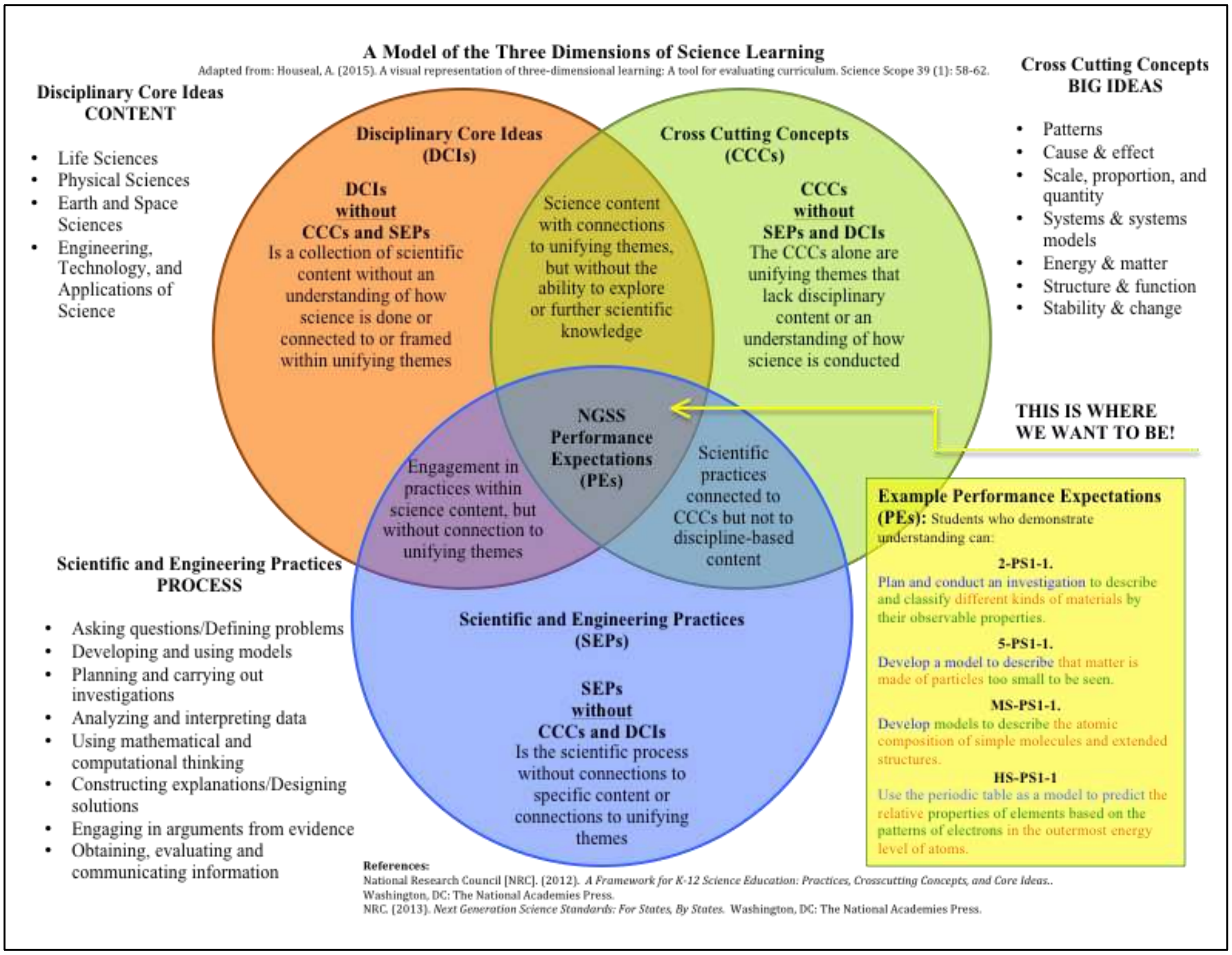


Figure 1. A Model of the Three Dimensions of Science Learning (Houseal, 2015).

There have been several approaches undertaken by researchers and professional development specialists to help teachers meet all these aspects of the NGSS (e.g., NSTA's *NGSS Hub* at ngss.nsta.org, *Stem Teaching Tools* at stemteachingtools.org, and *Ambitious Science Teaching* at ambitiousscienceteaching.org). In 2017, a team of learning scientists and teacher leaders started the Next Generation Science Storylines project. The project's goal is to guide teachers in developing coherent three-dimensional (3D) storylines in their classrooms (Next Generation Science Storylines, 2017). The team describes storylines as follows:

> A storyline is a coherent sequence of lessons, in which each step is driven by students' questions that arise from their interactions with phenomena. A student's

> goal should always be to explain a phenomenon or solve a problem. At each step, students make progress on the classroom's questions through science and engineering practices, to figure out a piece of a science idea. Each piece they figure out adds to the developing explanation, model, or designed solution. Each step may also generate questions that lead to the next step in the storyline. Together, what students figure out helps explain the unit's phenomena or solve the problems they have identified. A storyline provides a coherent path toward building disciplinary core idea and crosscutting concepts, piece by piece, anchored in students' own questions (Next Generation Science Storylines, 2017, Page “Storylines: What Are Storylines?”)

This definition highlights a method that provides a way for a teacher to make their classroom a place of science. Here, students engage in science as consumers and producers of knowledge, rather than just being consumers of knowledge or recipients of facts.

Statement of the Problem

Despite the abundance of evidence in support of 3D learning, in my research I have found a relative dearth of curriculum materials that actually capitalizes on this change in perspective. As schools move to align science curriculum with the three dimensions of the NGSS, educators are looking for ways to adjust their teaching and create authentic science experiences for their students but they are finding few resources. The sheer magnitude of the task of finding, adapting, and creating new curricular materials to support this 3D approach can be daunting at best (Next Generation Storylines, 2017).

Furthermore, as teachers become familiar (initially) with the scope and depth of the standards, it is quickly apparent, that unlike standards in the past, these cannot be “covered” individually. Thus, many find it to be a very time-consuming and seemingly impossible task. Treated individually, these standards, which explicitly include content with practices and big ideas (the DCIs, SEPs, and CCCs), would undoubtedly be impossible for any teacher to implement. This necessitates the bundling (or grouping) of related standards so coherent units can be taught that incorporate each of the bundled standards while capitalizing on the relationships among them (Bundling the NGSS, 2016)

Purpose

This project sought to document the creation process of a unit using an anchoring storyline, as outlined at nextgenstorylines.org. This eighth grade Earth and Space Science unit was designed to effectively incorporate all three dimensions of the Next Generation Science Standards. It included *anchoring phenomena* and a *dynamic science storyline* (Krajcik, Codere, Dahsah, Bayer, and Mun, 2014). The unit is designed to allow students to move into the role of scientists and allow the teacher to act as a partner in their journey to understanding. It taps into students' innate sense of curiosity and allows them to pursue their own understanding of the big ideas of Earth and Space Sciences. This project sought to add cohesive and coherent materials available to teachers using the three dimensions of the NGSS and the science storylines method.

Research Questions

The research questions that guided this project were:

1. What can be learned about the process of developing an eighth grade Earth and Space Science phenomenon-based storyline unit using all three dimensions of the Next Generation Science Standards by a practicing teacher?
2. How can the lessons learned from the development of this unit help others to do similar work?

3. What are the benefits and challenges related to this process of unit development?

Significance

Due to the fact that the NGSS are fairly new, there are relatively few well-designed units available for teachers to use. Furthermore, it is a large undertaking for teachers to incorporate all three dimensions into their science instruction. It is hoped that this documentation of the journey of a practicing teacher in the design and implementation of a 3D NGSS-aligned unit provides a clearer picture of the process. It is also intended to reveal the benefits and challenges of using the storylines method to accomplish this goal.

Chapter 2: Literature Review

Background

Since science first appeared in the United States education system in the 1800s, it has gone through many reforms. Arguably, one of the most comprehensive reforms has come very recently with the publication of *A Framework for K-12 Science Education* (NRC 2012), hereafter referred to as the Framework, which informed the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013). The Framework proposed that science education include much more than just content. To meet the vision of the Framework and the NGSS, students must engage in Scientific and Engineering Practices (SEPs), Disciplinary Core Ideas (DCIs), and Crosscutting Concepts (CCCs). This 3D aspect of the NGSS is the key to providing a rich learning environment for students in science.

The three dimensions are discussed in detail in both the Framework and the NGSS. The SEPs are the same practices that research scientists engage in to figure out how the natural and human-made world works and how engineers solve problems by designing and building systems. In this way, they are an extension and an enhancement to what was previously considered inquiry (NRC 2012). The DCIs are the key ideas, or content, in science that cover the four areas of Physical Science, Life Science, Earth and Space Science, and Engineering (NRC 2012). Finally, the CCCs are the major concepts that span all areas of science and are critical components to any scientific field (NGSS Lead States, 2013). In this framework, they are meant to help students understand the broad connections between the various scientific disciplines. Figure 2 provides a complete list of all of the SECs, CCCs and DCIs.

BOX S-1

THE THREE DIMENSIONS OF THE FRAMEWORK

1 Scientific and Engineering Practices

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

2 Crosscutting Concepts

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

3 Disciplinary Core Ideas

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

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

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

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

Figure 2. The three dimensions of the Framework (NRC, 2012, p. 3).

The NGSS incorporates all of the dimensions into specific Performance Expectations (PEs) that are statements that indicate what students should be able to do by the end of the instructional sequences in various grades. For any science unit, a teacher needs to be familiar with the PEs and the particular aspects of the 3-dimensions of the Framework that apply to the unit being taught (NGSS Lead States, 2013). Figure 3 shows an example of a physical science PE that is part of the topic of Energy. Included in the figure are the related DCIs, SEPs, and CCCs that should be incorporated during the instruction of that PE.

Performance Expectation	Science and Engineering Practices (SEPs)	Disciplinary Core Ideas (DCIs)	Crosscutting Concepts (CCCs)
MS-PS3-1: Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object. [Clarification Statement: Emphasis is on descriptive relationships between kinetic energy and mass separately from kinetic energy and speed. Examples could include riding a bicycle at different speeds, rolling different sizes of rocks downhill, and getting hit by a wiffle ball versus a tennis ball.]	**Analyzing and Interpreting Data:** Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. - Construct and interpret graphical displays of data to identify linear and nonlinear relationships.	**PS3.A: Definitions of Energy:** Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.	**Scale, Proportion, and Quantity:** Proportional relationships (e.g., speed as the ratio of distance traveled to time taken) among different types of quantities provide information about the magnitude of properties and processes.

Figure 3. An Example of all the components of an NGSS performance expectation (NGSS Lead States, 2013).

The new direction being promoted by the Framework and the NGSS will require a significant change to the way many educators teach science. Classrooms that follow the vision of the Framework will look considerably different from traditional science classrooms of the past which will result in a richer experience for students (NRC, 2012). The implications of this new vision are outlined by the NRC in Figure 4.

SCIENCE EDUCATION WILL INVOLVE LESS:	SCIENCE EDUCATION WILL INVOLVE MORE:
Rote memorization of facts and terminology	Facts and terminology learned as needed while developing explanations and designing solutions supported by evidence-based arguments and reasoning.
Learning of ideas disconnected from questions about phenomena	Systems thinking and modeling to explain phenomena and to give a context for the ideas to be learned
Teachers providing information to the whole class	Students conducting investigations, solving problems, and engaging in discussions with teachers' guidance
Teachers posing questions with only one right answer	Students discussing open-ended questions that focus on the strength of the evidence used to generate claims
Students reading textbooks and answering questions at the end of the chapter	Students reading multiple sources, including science-related magazine and journal articles and web-based resources; students developing summaries of information.
Pre-planned outcome for "cookbook" laboratories or hands-on activities	Multiple investigations driven by students' questions with a range of possible outcomes that collectively lead to a deep understanding of established core scientific ideas
Worksheets	Student writing of journals, reports, posters, and media presentations that explain and argue
Oversimplification of activities for students who are perceived to be less able to do science and engineering	Provision of supports so that all students can engage in sophisticated science and engineering practices

Figure 4. A New Vision for Science Education: Implications of the Vision of the Framework for K-12 Science Education and the Next Generation Science Standards (NRC, 2015).

The NGSS do not give specific guidance on what instructional strategies should be used to help students meet these PEs, as it is not intended to be a curriculum. Coming up with the curriculum is left up to curriculum directors, teachers, and researchers, some of whom have come up with ways to address this need (Pruitt, 2014). One of the most comprehensive strategies has been proposed by Krajcik, Codere, Dahsah, Bayer, and Mun (2014) where they outline a ten-step process to help teachers develop sequential lessons that will allow their students to build proficiency in selected NGSS PEs as shown in Figure 5.

Step 1:	Select PEs that work together—a bundle—to promote proficiency in using the ideas expressed. Often the bundle will include PEs from a single NGSS topic (see topic arrangement) or DCI (see DCI arrangement), but a bundle could draw in PEs from other topics or DCIs.
Step 2:	Inspect the PEs, clarification statements, and assessment boundaries to identify implications for instruction.
Step 3:	Examine DCI(s), science and engineering practices, and crosscutting concepts coded to the PEs to identify implications for instruction.
Step 4:	Look closely at the DCI(s) and PE(s). What understandings need to be developed? What content ideas will students need to know? What must students be able to do? Take into consideration prior PEs that serve as the foundation for cluster of PEs the lessons will address.
Step 5:	Identify science and engineering practices that support instruction of the core ideas. Develop a coherent sequence of learning tasks that blend together various science and engineering practices with the core ideas and crosscutting concepts.
Step 6:	Develop lesson level PEs. Lesson level expectations guide lesson development to promote student learning; they build to the level of understanding intended in the bundle of PEs.
Step 7:	Determine the acceptable evidence for assessing lesson level performances, both formative and summative.
Step 8:	Select related Common Core Mathematics Standards (CCSS-M) and Common Core Literacy Standards (CCSS-L).
Step 9:	Carefully construct a storyline to help learners build sophisticated ideas from prior ideas, using evidence that builds to the understanding described in the PEs. Describe how the ideas will unfold. What do students need to be introduced to first? How would the ideas and practices develop over time?
Step 10:	Ask: How do the task(s)/lesson(s) help students move towards an understanding of the PE(s)?"

Figure 5. Ten-step process to guide teachers in developing a sequence of lessons to build student proficiency in a bundle of PEs (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014, p. 163).

Some of the key ideas in this process include (a) needing to bundle standards, (b) making sure to examine the PEs and DCIs to understand them completely, (c) determining which SEPs and CCCs can be incorporated, (d) determining what evidence will be used to assess student learning, (e) constructing a storyline, and finally (f) evaluating the effectiveness of the lesson. It is the idea of constructing a storyline, however, which is the key to determining how the understandings will be acquired by students (Reiser, 2017).

Science Storylines and Phenomenon-Based 3-D Learning

Development of Storylines. Storylines focus on the use of interesting, thought-provoking phenomenon to get students to engage in authentic investigations (Reiser, 2017). A storyline is built starting from students' initial models and unresolved questions about a phenomenon. The teacher uses student questions to develop the activities and investigations to answer those questions and come up with new questions (Turley, Trotochaud, & Campbell, 2016).

Because the idea of using storylines to meet the vision of the NGSS is new, there are few resources available for teachers to learn about the process. However, researchers have begun to add to the literature on methods for creating and using storylines in the science classroom. There are a few examples that are beginning to show up in science education practitioner journals and on websites like Nextgenstorylines.org created by Brian Reiser, who was a member of the committee authoring the Framework.

Dr. Reiser (2017) outlined the steps of creating a science storyline in this order:

1. Students observe a phenomenon and ask questions.
2. The teacher assists in determining the scientific practices students will engage in to answer the questions.
3. After engaging in those practices, students determine what has been figured out.
4. These discoveries become parts of the DCIs and CCCs that students are building.
5. Develop new questions based on this part of the investigation.
6. The process repeats.

Figure 6 depicts Reiser's illustration of the procedure.

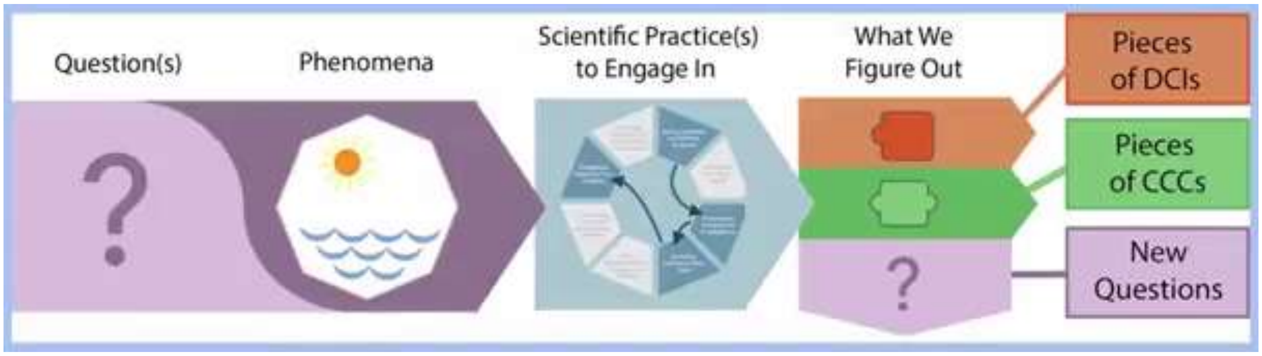


Figure 6. The Steps to the Storyline Process (Reiser, 2017).

In this process, it is important for teachers to understand that they should not just tell their students that they are going to be doing an investigation on a specific topic. Instead, they should present or have the students discover a phenomenon that will pique their natural curiosity, and elicit students' questions (Reiser, 2017). This is the basis of phenomenon-based learning. Teachers can help them investigate their questions in a methodical way. This will bring up new questions, which will lead to new investigations. It is important for the teacher to anticipate possible questions that might come up so they can have investigations and data ready ahead of time. Student work is guided by the questions that are generated initially and as the unit progresses (Reiser, 2017).

By using this process, students gain a deeper and multifaceted understanding of the topic and how to conduct actual science. This allows them to meet the PEs with a more lasting understanding. At the end of the unit, students should easily be able to show what they have learned compared to what they understood before the unit (Turley, Trotochaud, and Campbell, 2016).

Challenges to developing storylines. This raises a concern from teachers, who may feel they always have to have a plan or new phenomenon for the next or investigation. The teacher does have to carefully guide the lesson in the direction that makes sense within the storyline.

Because of this, it initially seems overwhelming to make sure everything in the unit is completely in place ahead of time. The teacher does need to spend a significant amount of time initially analyzing and gaining a strong understanding of the PEs that are bundled in the unit, and, using the ten-step process outlined earlier helps with this process. The payoffs come during implementation, when students themselves begin to understand “when and how to seek and build knowledge” for themselves (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014). The teacher will then be able to move into a facilitative role where they guide student sense-making rather than just delivering information.

Ambitious Teaching

History and definition. In order to make the science storyline method work, teachers need to create a classroom environment in which their students can engage in authentic science. This idea has been named “ambitious teaching”, with a goal of ensuring that every student is actively engaged with the subject matter and can apply what they have learned. It has its roots in an idea that John Dewey promoted over 100 years ago of “psychologizing” the subject matter. According to Smith and Girod (2003), Dewey realized teachers were best suited to "reinterpret the fundamental concepts and methods of the respective disciplines in accessible, engaging, and powerful ways for students” (p. 295). No one has a better perspective of individual students’ backgrounds and needs than the teacher (Smith & Girod, 2003), thus their understanding of how students learn allows them to develop experiences that will be meaningful and engaging for every student. This “student experience” needs to be prioritized when developing instruction rather than just relying on thoughtfully designed curricula.

Practices and examples. In science, ambitious teaching is not only the teaching of scientific concepts, but it is also giving students opportunities to apply their understanding to solving or better understanding authentic scientific quandaries (Smith & Girod, 2003). Ambitious teaching in science seeks to make the classroom a place where students perform authentic scientific investigations using the knowledge they have.

Teachers can use four practices of ambitious teaching to make their classrooms a "place of science". The practices are:

1. Identify a big idea and anchor it in a phenomenon that students need to explain;
2. Elicit students' ideas to activate prior knowledge and adapt instruction;
3. Help students collect and use evidence to better explain the anchoring phenomenon; and
4. Press students for evidence-based solutions (Stroupe, 2017, p. 460).

These critical practices reinforce the ideas from the storylines method and need to take place in order to achieve positive outcomes with this type of learning (Windschitl, Thompson, Braaten, & Stroup, 2012).

Connections to storylines. The vision of the NGSS and the Storylines project is to get students involved in the actual science behind the concepts. Research shows that students in classrooms that use ambitious teaching have more authority over their learning and are more likely to discuss their ideas in public (the classroom). They are also more connected to the science because they have an active role in what is being investigated and the choice of methods for investigating it. Teachers who use teacher-directed instruction tend to have students who are more concerned in what is right or wrong and not in the practice of finding out (Stroupe, 2014). Thus, it is important for teachers to be purposeful in allowing students to be the drivers for the science being done.

Student Discourse

Giving students opportunities to talk about their understanding is an important way for them to evaluate their own thinking. Students use their own background knowledge, archival and experimental data, and shared understandings of their peers to create possible explanations. This mirrors what research scientists do more than what usually takes place in science classrooms. Radinsky Oliva, & Alamar (2010) point out that:

> When students (like scientists) leverage peers' language to clarify concepts, the offerings of multiple students become ''texts'' with which the members of the class can construct inter-textual connections, which in turn can serve as resources for converging on shared conceptualizations of the complex science ideas being discussed (p. 636).

Students use others' ideas revealed through classroom discourse to construct a solid understanding of the concepts in their own minds.

The idea of students using talk to help one another to deeply understand concepts stems from the work of Thomas Kuhn (1962), where he talked about the importance of scientific rhetoric not only between scientists but also between students who are involved in the discovery of scientific concepts. It is critical for students to have opportunities to share their ideas with their peers. It is also important for the teacher to facilitate the discourse so it becomes "shared intellectual property" in which everyone in the class has ownership (Radinsky, Oliva, & Alamar, 2010).

It is important to allow discourse to continue even if a student's idea might be fundamentally incorrect initially. This is because of the importance of making everyone's ideas public so the teacher and students can hear what everyone is thinking. In a traditional classroom these ideas might just be corrected and the lesson would move on. However, Radinsky, Oliva, and Alamar (2010) point out that, "it is easy to overlook substantive scientific thinking in children's ideas when we too quickly dismiss 'misconceptions' as simply wrong" (p. 636). When allowed to elaborate, students will often share valuable ideas which would otherwise remain unknown. When well-managed and guided, the class will eventually get to the *correct* answer, but the students will have a greater understanding and will have internalized that understanding.

Analogous Thinking and Recognizing Relationships

As an important part of the 3D aspect of the NGSS, teachers need to help students think of science knowledge as an interrelated system that can be adapted to new situations instead of individual discrete bits that do not connect. Analogies function "as a way for students to draw relationships between target scientific phenomena and more easily represented laboratory materials, visual representations, models, or well-understood scientific phenomena" (Richland & Simms, 2015, p. 184). In addition, analogies help students understand "the natural and human-built world as complex systems of relationships that may be further compared, contrasted, integrated, or otherwise explained" (Richland & Simms, 2015, p. 184). An example is the use of a scale model of the solar system to make observations about the actual solar system. Students would need to understand the analogy between the model and the real solar system in order to apply observations from the model to actual solar system phenomena. They would need to understand what parts of the phenomenon are represented well by the model and what parts it is unable to account for.

Students can often see basic similarities between representations (e.g., various models of the solar system vs. the intricacies and vastness of the actual solar system) but they are less likely to make deeper connections between models and reality without help from the teacher. That is why teachers need to provide guidance and instruction to help students make connections and apply them analogically to new situations (Richland & Simms, 2015). In this way, teachers are "explicitly supporting [students] in connecting these models with aligned representations of the scientific phenomena" (Richland & Simms, 2015, p. 185).

Astronomy Education Best Practices

The best practices for teaching astronomy concepts from current literature were: working with misconceptions, constructing new knowledge on prior knowledge, and using models. While none of these practices are exclusive to astronomy education, they are worth taking into extra consideration here due to the abstract nature of space systems. The solar system is vast and most observations students have likely made up to this point have been earth-based and random. This can easily lead to preconceptions that may need to be challenged if they are to gain a deep understanding of how the system actually works (Bakas & Mikropolis, 2003; Trumper, 2001).

Misconceptions. Teachers need to be aware of personal understandings students bring to the classroom as they make connections. This is particularly true with astronomy concepts. The well-known video *A Private Universe* (Schneps, 1989) demonstrated that misconceptions about basic topics in astronomy can be pervasive in children and can last well into adulthood. It is important to understand that, "for children, misconceptions are knowledge and this knowledge is no different from any other knowledge they have constructed" (Bakas & Mikropoulos, 2003, p. 949). The views held by students are based on their own experiences, thus they use what they have seen and experienced to develop their interpretations (Bakas & Mikropoulos, 2003). Student misconceptions can be further compounded by the interchangeable use of terms, such as revolution/orbit/year, rotation/day, elliptical/circular orbit, which can cause even more confusion.

Constructivism. Constructivism is a philosophy about how students learn. In constructivism, the main belief is that students come to the classroom with experiential "knowledge". This knowledge may or may not be scientifically accurate, but teachers can help students refine or revise that information "by posing contradictions, presenting new information, asking questions, encouraging research, and/or engaging students in inquiries designed to challenge current concepts" (Brooks and Brooks, 1999). This can be especially necessary in the area of astronomy where students' only experience comes from a basic earth-based perspective (Bailey & Slater, 2004).

> The key aspects of constructivism that should influence the materials for developing student teachers' understanding, can be expressed as the need:
>
> a. to have knowledge of students' existing understanding in the targeted conceptual areas and to use this as a starting point for the design of appropriate teaching materials;
> b. for students to become aware of their own views and uncertainties;
> c. for students to be confronted, afterwards, with the currently accepted concepts;
> d. to provide experiences that will help students to change their views and conceptions, and accept the scientific view (Trumper, 2001, p. 1119).

This requires the learner to recognize their currently held ideas and decide whether to change them. Thus, the experiences directed by the teacher need to be compelling enough to convince students to make that change in their understanding (Trumper, 2001). These experiences in astronomy might include night-sky/sunset/sunrise observations, videos, Internet resources, and models.

Using models. One way to help students change pre-conceptions is to use models. Researchers have found a great deal of evidence that the use of models to explore space phenomenon results in a deeper and more lasting understanding of the concepts by students (Bailey & Slater, 2003; Bakas & Mikropoulos, 2003; French & Burrows, 2017; Slater & Gelderman, 2017; Trumper 2001 & 2005). Models include detailed illustrations and diagrams, physical 3D scale models, planetarium projections, computer generated simulations, 3-D virtual reality models, and students kinesthetically modeling the phenomena. Whatever their form, they should be "sense-making tools that help us predict and explain the world" and they must "embody ideas about how and why the phenomenon occurs or about components and relationships on the system being studied" (Schwarz, Passmore, & Reiser, 2017, p. 114).

Possibly one of the most effective models for learning about Earth and Space Science is when students kinesthetically model the phenomena. Researchers have found compelling evidence that students can achieve a greater intuitive grasp of space science concepts by modeling the movement and arrangement of objects in the solar system with physical movements of the students' bodies. These concepts would be difficult to learn in more conventional ways such as via textbooks or computer animations (Morrow, 2000). This method can help students to kinesthetically experience important space phenomena. These models include: exploring the direction Earth must turn for the Sun and stars to rise in the East; why the Sun is higher in the sky in summer; why we see different stars at different times of year; and the cause of seasons (Morrow, 2000).

Action Research

Putting this theory into practice and determining its effectiveness requires action research. Action research is a study done specifically to improve upon a personal practice that is currently being used by the researcher (Falk & Blumenreich, 2005). Sagor (2003) defines it as, "a disciplined process of inquiry conducted *by* and *for* those taking the action" (p. 3). Essentially, the researcher defines an issue that is important to them, tries something new, and analyzes and reflects on the effects of that new action. In education, "action research is not about learning why we do certain things, but rather how we can do things better. It is about how we change our instruction to impact students" (Ferrance, 2000, p. 3).

Both Sagor (2000) and Ferrance (2000) describe action research as a cyclical process that begins with the practitioner identifying a problem or an area of focus, working through an investigation, and taking action based on the results. The following steps are a synthesis of the process as outlined by the two authors:

1. Select a focus or identify a problem that is meaningful to the practitioner.
2. Clarify what theories or methods the practitioner feels might be most effective.
3. Develop personally meaningful research questions
4. Collect data using triangulation to enhance the reliability and validity of findings.
5. Analyze and interpret data to answer these two questions:
    a. What is the story told by these data
    b. Why did the story play out this way? (Sagor, 2000, p. 6).
6. Report on the results to other interested parties.
7. Act on the evidence discovered in the investigation.
8. Evaluate the results of the action (Ferrance, 2000 & Sagor, 2000).

This investigation "continually evolves as the action under study is tried, analyzed, implemented, and investigated over and over again" (Falk & Blumenreich, 2005, p. 16).

Data collection is one of the most important parts of this process, yet it can also be the most problematic. Data needs to come from multiple sources (e.g., field notes, surveys, anecdotal records, video analysis, checklists/logs, assessments, etc.) to reliably and validly provide the best picture of the effectiveness of the actions being taken (Sagor, 2000). At least three independent sources of data (triangulation) should be used for the basis of any actions or recommendations being made (Ferrance, 2000). The data must be methodically sorted, sifted, organized, and examined to identify appropriate conclusions (Sagor, 2000).

Action research can be used to study the effects of applying different strategies and techniques. It can also be used to study the synthesis of several of these proven strategies and techniques as will be the case with this project. The literature supports the effectiveness of each of the practices individually. However, more research needs to be conducted to look at how they can be used together to increase student understanding in science.

Chapter 3 – Developing Background for Unit Creation

Introduction

With the publication of the Framework (2012), a new broad description of learning expectations for all K-12 students in science, was proposed. This was based on what we have learned about how students learn science best. The vision of the Framework is one “in which students, over multiple years of school, actively engage in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in these fields” (NRC, 2012, pp. 8-9). To do this, students need to be more than just consumers of science information and move toward participating in authentic science tasks.

In developing this unit, I synthesized work from both *Next Generation Science Storylines* developed by Reiser Lab at Northwestern University (2017), and T*ools for Ambitious Science Teaching* developed by Windschitl, Thompson & Braaten (2018). The combination of these endeavors provided the backbone and resources that were critical to the creation of this unit.

Determining Which Standards to Bundle for the Unit

In order to prepare for this unit, I had to determine what I wanted the unit to include. The first place I looked was on the NGSS website (http://www.nextgenscience.org). I went to the middle school section to the *MS. Space Systems* bundle. This bundle (purposeful group of standards) included three standards. I also reviewed the NGSS Hub at the National Science Teachers Association website (https://ngss.nsta.org/AccessStandardsByTopic.aspx). This site provided a slightly more interactive view of all the components of each standard within each topic area.

Next, I looked for standards in other topic areas to see if there were others I could tie into this unit to help students make connections. I realized that I could use Newton’s Laws of Motion and gravitational interactions standards from my Forces and Interactions unit. These additional standards would help students understand the motions within our solar system and galaxy.

Determining Which SEPs and CCCs Will Be Focused on to Obtain Understanding of DCIs

Once I determined the standards, I had to interpret the DCIs that students would need to understand in conjunction with the SEPs, and CCCs that help students gain these understandings. Fortunately, much of this work has already been done and is available on the NGSS interactive website and NGSS@NSTA. The CCCs and SEPs that I chose to use are included in Figures 7, 8, and 9. These figures also include connections to the Nature of Science.

Performance Expectation	Science and Engineering Practices (SEPs)	Disciplinary Core Ideas (DCIs)	Crosscutting Concepts (CCCs)
MS-ESS1-1: Develop and use a model of the Earth-sun-moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons.	**Developing and Using Models:** Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. Develop and use a model to describe phenomena.	**ESS1.A: The Universe and Its Stars:** Patterns of the apparent motion of the sun, the moon, and stars in the sky can be observed, described, predicted, and explained with models. **ESS1.B: Earth and the Solar System:** This model of the solar system can explain eclipses of the sun and the moon. Earth's spin axis is fixed in direction over the short-term but tilted relative to its orbit around the sun. The seasons are a result of that tilt and are caused by the differential intensity of sunlight on different areas of Earth across the year.	**Patterns:** Patterns can be used to identify cause-and-effect relationships. **Connections to Nature of Science:** Scientific knowledge assumes an order and consistency in natural systems *Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation.

Figure 7. NGSS for the Earth-Moon-Sun System.

Performance Expectation	Science and Engineering Practices (SEPs)	Disciplinary Core Ideas (DCIs)	Crosscutting Concepts (CCCs)
MS-ESS1-2: Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.	**Developing and Using Models:** Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. Develop and use a model to describe phenomena.	**ESS1.A: The Universe and Its Stars:** Earth and its solar system are part of the Milky Way galaxy, which is one of many galaxies in the universe. (MS-ESS1-2) **ESS1.B: Earth and the Solar System:** *The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them. *The solar system appears to have formed from a disk of dust and gas, drawn together by gravity.	**Systems and System Models:** Models can be used to represent systems and their interactions. **Connections to Nature of Science:** Scientific knowledge assumes an order and consistency in natural systems *Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation.

Figure 8. NGSS for the Role of Gravity in the Motions within Galaxies and the Solar System.

Performance Expectation	Science and Engineering Practices (SEPs)	Disciplinary Core Ideas (DCIs)	Crosscutting Concepts (CCCs)
MS-ESS1-3: Analyze and interpret data to determine scale properties of objects in the solar system.	**Analyzing and Interpreting Data:** Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. Analyze and interpret data to determine similarities and differences in findings.	**ESS1.B: Earth and the Solar System:** The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them.	**Scale, Proportion, and Quantity:** Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small. **Connections to Engineering, Technology, and Applications of Science:** Interdependence of Science, Engineering, and Technology *Engineering advances have led to important discoveries in virtually every field of science and scientific discoveries have led to the development of entire industries and engineered systems.

Figure 9. NGSS for the Scale Properties of Objects in the Solar System.

Determining Essential Questions and Understandings

Once the standards (and their related DCIs, CCCs and SEPs) had been determined, I needed to parse out the unit's essential (or enduring) understandings. Wiggins and McTighe (1998) define these as, "the important understandings, that we want students to 'get inside of' and retain after they've forgotten many of the details." (p. 10). The process I used was similar to the one detailed on the University of Washington's *Tools for Ambitious Science Teaching* website (Windschitl, Thompson & Braaten, 2018). Using the standards bundle as my guide, I began by writing four essential questions for my students to answer with a detailed and thoughtful explanation. They were:

1. What is it about the earth, moon, and sun system that causes solar and lunar eclipses, moon phases, and seasons?
2. Why do we see different things in the sky during different parts of the day, night, and year?
3. Where is our place in the universe?
4. How can we create a conceptual model (drawing, physical, kinesthetic, etc.) that can explain all of these phenomena?

I wanted these questions to engage students over time and not just for a class period.

Next, I wrote out an explanatory narrative of all of the interconnected concepts needed to explain the phenomenon. Windschitl, Thompson & Braaten (2018) refers to this as a *gapless explanation*. I turned this narrative into a descriptive list of the essential understandings students would need and color-coded the main conceptual areas which I refer to as strands. Finally, I reorganized this list in an attempt to find the best initial flow for the unit so that all the topics could be taught in an order that made sense. The predetermined flow was a guideline because the interests and questions of the students would inevitably take the storyline in different directions. The final list of essential understandings is shown in Figure 10.

Strand	Essential Understanding
Gravity/Inertia	The solar system appears to have formed from a disk of dust and gas, drawn together by gravity.
Gravity/Inertia	The earth, other planets, moons, dwarf planets, asteroids, comets, and Oort Cloud objects all revolve around the sun because of the interaction of the sun's gravity on those objects and the inertia of each of those objects.
Gravity/Inertia	Moons revolve around planets because of the planet's gravity and the moons' inertia.
Rotation/Revolution	All of the movements of objects in the solar system are cyclic and predictable.
Rotation/Revolution	Phenomena observed in the day and night sky are affected by the revolution and rotation of the earth and the revolution of the moon around the earth.
Rotation/Revolution	The apparent movement of the sun, moon, planets, and constellations from east to west across the sky is caused by the rotation of the earth.
Rotation/Revolution	The shift of different visible nighttime constellations throughout the year is caused by the progression of the earth around the sun and its relative position to the sun throughout the year.
Moon Phases	One half of the moon is always lit by the sun. However, as it revolves around the earth, we are able to see it from different perspectives during the night throughout the month and this causes the phases that we see. The moon's relative position to the sun and the earth allows us to see different amounts of the lit half of the moon as the month progresses. This cyclic procession of moon phases repeats approximately every 28 days because this is the amount of time it takes the moon to make one full revolution around the earth.
Eclipses	Both lunar and solar eclipses are caused by the arrangement of the earth and moon in relation to the sun.
Eclipses	During solar eclipses, the moon moves between the sun and the earth and causes a shadow over a small portion of the earth's surface while blocking the sun for those people in that small area. This shadow sweeps across the earth as the moon moves by.
Eclipses/Scale	The sun's diameter is approximately 400 times larger than the moon's diameter, but because it is about 400 times farther away from Earth, they both appear to be approximately the same size as viewed from Earth. This allows the moon to just barely cover the sun during a solar eclipse. This is why the path where the eclipse is visible on Earth is so narrow.
Eclipses	During a lunar eclipse, the moon travels through the shadow of the earth, which blocks the light from the sun from reaching the moon's surface. During full lunar eclipses, the moon will appear red due to the refraction of light through the edges of Earth's atmosphere.
Seasons	Seasons are caused by the relative tilt of the earth in comparison to the sun. This tilt stays the same all the time, but that causes different parts of the earth to receive different amounts of sunlight (both time and intensity) as it progresses around the sun. Thus, during different parts of the year, different parts of the earth are warmer or cooler than other parts causing seasons.
Seasons	The fact that the earth's orbit is slightly elliptical (closer to the sun during some parts of its orbit than others) has no effect on the Earth's seasons. The aphelion (farthest point to sun) and perihelion (closest point to sun) of Earth changes over time. Currently, perihelion is around January 2 and aphelion is around July 6, which matches with the southern hemisphere seasons.
Scale	We can see several planets in our solar system with the naked eye and even more with telescopes. Even though they are very large in size, they appear very small because of their huge distance from Earth. Stars are a more extreme example of this.
Scale	These distances and the sizes of the planets can be modeled to scale here on Earth. However, it is difficult to show the relative distances to scale at the same time as showing the object sizes to scale.

Figure 10. Essential Understandings for the Space Systems Unit.

Selecting an Anchoring Phenomenon

To start the unit in a way that would elicit my students' prior knowledge (including misconceptions), I chose anchoring phenomena that would be both contextual and complex to explain. I used the 2017 Great American Eclipse as my initial anchoring phenomenon. I also decided to include the 2018 Super Blue Blood Moon lunar eclipse as a point of comparison. Both phenomena are interesting and thought-provoking and I knew they would lead to quality discussions and give direction to the unit. I hoped that the exploration of these phenomena and the process of understanding their cause could lead to the understanding of most, if not all, of the essential understandings determined earlier.

Brainstorming Potential Student Questions

As an added step, I felt that it was important for me to brainstorm questions that students might ask during each section, or strand, of the unit. This allowed me to think about ways to adapt lessons so that I could help students discover those answers. I also wanted to have a list of questions that I might pose to help steer the discussion if they students did not come up with them, initially.

There was no way to anticipate all of the questions students might have. However, the questions I developed were the ones I needed to guide students to investigations that would help them materialize the essential understandings. These questions (see Appendix B) became guiding questions for the unit. It is important to note that even though all essential understandings will be covered in a unit, some student questions may not be answered. However, students will have gained the tools necessary to seek out their own answers to these questions.

Data Sources and Documentation of the Process

I began by documenting the process of the initial planning, which included the bundling of standards, determination of SEPs and CCCs, resources needed, time taken, and difficulties encountered. I also documented the incremental planning and lesson development as the unit progressed. I looked for unexpected directions taken because of class discourse, future changes needed, the process of finding materials or phenomena to guide student understanding and the tools used and how useful they were. Finally, I tried to gauge the impact on learning as compared to the way I taught the unit in past years.

I kept field notes about the process of developing the unit to help me keep track of this information. I also completed a daily reflection sheet which I developed to use as I taught the unit (see Appendix A). I designed this so I could go back and look more closely at my teaching methods. I also recorded my teaching and interactions using a Swivl™ robot and iPad. This is a device used in various classrooms at our middle school and I was able to borrow it from the library for the entire seven weeks.

I also was fortunate to have a teaching partner who was willing to teach the unit to her two eighth grade classes. She gave me some valuable feedback. Since she had not participated in the lesson development she had to use the teacher guides I created. This not only gave her a chance to try a new teaching method, but it also gave me insight on how well my lesson design could work for others.

Chapter 4 - Unit Creation

Development of the Initial Storyline Skeleton

The storyline skeleton is a general plan for a logical flow of the unit. It outlines the order in which phenomena and activities will be introduced to meet the essential understandings. It is important to recall that the order and progression of the storyline can change depending on the needs of the students and questions they have. In this process, the students are in the driver's seat with the teacher guiding them to build the story that explains the phenomena. Until I taught the unit for the first time, I did not know the exact path that it would take. In fact, this will be the case each time the unit is taught with different students having different interests and needs. Nonetheless, this process helped me prepare so that I would be able to guide the students.

In developing the initial storyline, I began by thinking about the big questions and the lessons that would be needed to answer those questions. Using the essential understandings (Figure 10), I considered the lessons and activities I already had in my repertoire and what I would need to create or modify to fill gaps. I wanted to ensure students would gain a thorough understanding of each of these important concepts. I listed these lesson ideas in the same order as these essential understandings.

Reiser (2017) outlines five classroom routines that help ensure 3D learning. These include the anchoring phenomenon, navigation, investigation, problematizing, and putting pieces together routines. They are explained in more detail in Figure 11. As I listed my lesson ideas, I noted which of the classroom routines each lesson would follow.

It is important to note that this was just a preliminary analysis of my thinking on the opportunities I could provide for students to learn the concepts. I revised my storyline many times as I developed the lessons for the unit. This initial attempt was just a chance for me to get my ideas down as a starting point for the unit development. The final storyline skeleton outlining the fifteen lessons contained in this unit was completed after all of my lessons were developed (see Appendix C).

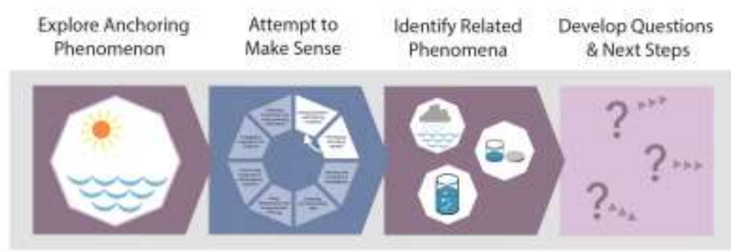
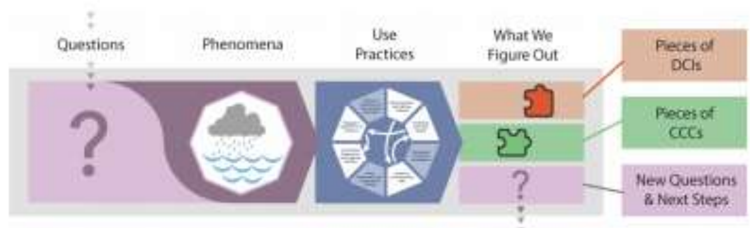
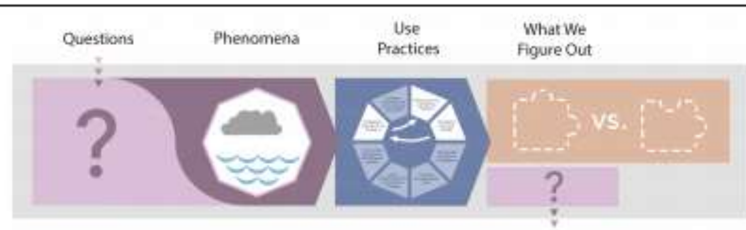
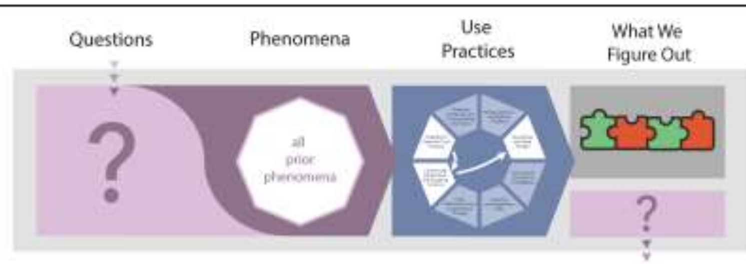
Question	Routine	Elements
How do we kick off investigations in a unit?	*Anchoring Phenomenon Routine*	
How do we work with students to motivate the next step in an investigation?	*Navigation Routine*	
How do we help students use practices to figure out pieces of the science ideas?	*Investigation Routine*	
How do we push students to go deeper and revise the science ideas we have built together so far?	*Problematizing Routine*	
How do we help students put together pieces of the disciplinary core ideas and crosscutting concepts?	*Putting Pieces Together Routine*	

Figure 11. Storylines: 5 Questions/Classroom Routines to Bring 3-Dimensional Learning into Our Classrooms (Next Generation Science Storylines, 2017)

Lesson Development

To develop each lesson, I began by using a modified version of the template illustrated on the Next Generation Science Storylines website (2017). As with the original template, it includes the following sections: *what we are doing now*, the *lesson question*, the *time required* for the lesson, the *standard* being addressed, the *phenomena* being explored, the *performance expectation*(s) color-coded to show the three dimensions, *what we figure out*, *resources*, and *what will likely come up next*. I added a section to the template explaining what we had learned in previous lessons that could be used as background. I also modified the *What We Figure Out* section to include all of the activities, tools, etc. that we might use to increase our understanding of the phenomenon. I developed each of these sections in a specific order to make it easier for me to make sure I was covering everything as thoroughly as possible. An example is shown in Figure 12 and the complete set of lessons is shown in Appendix D.

☀ Strand 1 of the Storyline: Effect of Gravity on the Movement of Solar System Objects

Previous Lesson - Where we have been: In our previous Forces and Interactions unit, we learned that gravity is an attractive force between all objects that is affected by mass and distance. We also learned that all objects have inertia, which is the object's resistance to any change in its motion. Furthermore, we learned that objects in motion have momentum and objects that are changing direction (turning) are accelerating. Finally, we learned that mass that is accelerating involves force.

This Lesson - What we are doing now: Using archival data, animations, simulations, and kinesthetic modeling, students will discover that orbital motions within our solar system and our galaxy are caused by the interactions of those objects' centrifugal force (caused by their angular momentum) and the gravitational force between them and a central body such as the sun, a planet, or a black hole. Students will use prior knowledge from previous lessons to develop and revise models of the movements within the solar system, and use these to explain the reason those motions exist.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), Resources, and Next Steps
L1: What is the role of gravity in the motions of objects like planets, moons, asteroids and comets within our solar system? 2 periods: (40 min each) *Building toward* ⬇ NGSS PEs: MS-ESS1-2	Through Earth-based and space-based observations, we see that all objects in our solar system revolve around some central body such as the sun or a planet. This same type of motion can be seen within entire galaxies as well.	Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system. Key: Blue - SEPs Green - CCCs Orange - DCIs	How Gravity Causes Circular Motion • Show video of solar system formation from dust and gas being drawn together by gravity: https://www.youtube.com/watch?v=Uhy1fucSRQI • Use the PHET Gravity and Orbits simulator (https://phet.colorado.edu/sims/html/gravity-and-orbits/latest/gravity-and-orbits_en.html) to explore how gravity and objects' velocity work together to create circular (or elliptical) motion. • Use the Gravity Simulator from Test Tube Games (http://www.testtubegames.com/gravity.html) to further explore how the initial velocity and the amount of gravity affects the motion of objects in simulated space. • Use a ball on a string spinning around overhead to model the Earth-Sun system. Have students predict which direction the ball will go if the string broke. Have them compare this model to the real system. • Use the gravity well to explore how the mass of objects affects the amount of gravity they produce, and how that gravity can affect the movements of other objects nearby. Next: What does the movement of different objects in our solar system actually look like?

Figure 12. Example lesson plan template adapted from Next Generation Science Storylines (2017).

I began by determining a phenomenon for each strand. Recall that phenomena are events or processes that take place; essentially, things that happen (Tools for Ambitious Science Teaching. 2018). I chose each phenomenon based on the essential understandings I had outlined for that strand. I tried to come up with a phenomenon that, once explored in detail, would lead to a strong understanding of the essential understanding(s) for this lesson. My other criterion was that the phenomenon had to be interesting enough so students would be enthusiastic to learn more about it. Yet, it also had to be complex enough that it would take a significant amount of effort for students to understand it.

Next, I created the lessons for the strand. Every strand had more than one lesson. To break the strand into lessons, I determined the main topics that would need to be explored in order to understand the phenomenon and these topics became each of my lessons. For this reason, and the fact that my class periods are only 43 minutes long, most of my lessons took more than one day to complete. I noted these topics at the top of the *What We Figure Out* section so it would be easily identifiable in case I needed to find it quickly. This could happen if students' interests or questions lead the storyline in a different direction than the one I had planned. This modularization of the storyline makes it easy to change direction and still be prepared for whatever comes up (mostly)!

After determining the topic for the lesson, I wrote a lesson question. This question was one that all students should be able to answer by the end of the lesson. In fact, I wanted them to be able to explain it scientifically to another person. The question was specific to the topic, but general enough that it could not be answered with a simple short explanation. It required students to think deeply and work together to come up with a detailed answer. Because my students were used to short fact-recall questions, being asked to formulate their own thoughts about a scientific concept was a high expectation. However, it was an opportunity I wanted every student to have.

Once I had a direction and purpose for the lesson, I needed to create activities that would allow my students to discover the answer to the lesson question. I included as many ideas for activities and resources as I could find, so I could select the ones that would meet the needs for my students in each of my classes. Some classes might only need some of them and others might need all of them. They could even be individualized for specific students as their needs were revealed over the course of the lesson. I put the activities in an order that made sense to me, but this order was always flexible based on the direction taken by the class. I tried to make each activity more student-centered than what I had traditionally done. I was able to use many of my prior activities, but I spent a fair amount of time thinking of how to turn them around so that the students were doing the work rather than me. Often my activities allowed students to look at evidence and data, and to experiment to arrive at a conclusion individually and as a group.

For each lesson I included two important summaries. The first was in the section titled *This Lesson-What we are doing now*. In this section I included a brief synopsis of what tools and strategies would be used by students, what they would discover during the lesson, and what major concepts they should be able to explain. This provided a way to quickly see what this lesson would entail. The second was in the section titled *Previous Lesson-Where we have been*. For this section I thought carefully about the background students would need to move forward with this lesson. I wrote this in a way to be sure that whatever path we took, students would have sufficient background to handle the activities. This process gave me a chance to reflect on prior lessons to make sure I was providing the background needed for future lessons. I actually went back and revised some lessons because of this reflection.

The last thing I did was to include what I thought should come next in the lesson sequence. I felt it was important to have this expressed in each lesson so I would be able to think ahead to what was coming up and it helped me make sure students were ready to move on to the next lesson. This meant I had to assess students either formally or informally within each lesson to make sure they were internalizing the important concepts. Most assessments were informal with a few specific formal assessments. If there were a formal assessment for a particular strand, I made sure to note it in the final lesson of that strand.

In total, I ended up with six strands broken into 15 lessons. I determined the minimum amount of time needed was 27 class periods (40 minutes) for the lessons and approximately eight to ten extra class periods for formative and summative assessment activities. This was quite a bit longer than the four weeks that my past unit had taken, but the benefit to student understanding made it worth the extra time.

Tools and Resources

One important aspect of unit planning is finding tools and resources to effectively engage students and enhance their understanding of the concepts. I spent a significant amount of time searching for ones I thought were educationally valuable. I also spent hours watching YouTube videos of educators who were doing amazing things with space education in their classrooms. My criteria were fairly simple: The tool or resource had to (a) be interesting and engaging for the level of my students, (b) be scientifically correct and minimize misconceptions, (c) enhance student understanding of an important concept, and (d) be better than other tools that might serve the same purpose.

Because science concepts about earth and space science are abstract and intangible, I selected tools and resources that allowed students to interact with objects and forces that would normally be impossible to interact with. These made it easier for students to make the conceptual leaps in their thinking that would allow them to solidify essential understandings. Figure 13 provides examples of resources and tools I used to enhance student understanding and to challenge their misconceptions.

Tools/Resources	**Examples/Description**	**Uses**
Multimedia	• Video and photographs taken from Earth • Video and photographs taken by satellites or astronauts	• View phenomena that might be impossible to see from our school setting • See views from Earth at other times of the year • Use time-lapse video to observe a phenomenon over a shorter time period • View phenomena from a different perspective than what we see on Earth
Archival data	• Websites such as https://www.timeanddate.com publish data in an easy to digest format which students can use.	• Archived data can be easily acquired by students from multiple resources • Data related to space phenomena is often unrealistic to collect by students • The data can be used by students to help make conclusions about a topic or to change their thinking.
Digital interactives	• Interactives from the PhET Interactive Simulations website (https://phet.colorado.edu/) • University of Nebraska's astronomy interactives website (http://astro.unl.edu/animationsLinks.html) • *Celestia* 3D solar system mapping software	• Makes it easier for students to visualize space phenomena by shortening the amount of time they take to unfold or by scaling down the huge distances involved • Makes events like moon phases, eclipses, seasons, and planetary motion tangible for students • Be sure to discuss what it most accurately shows and what might be less accurate about it as well
Classroom planetarium	• Using the classroom to represent space, a line was taped all the way around the classroom at student eye level to represent the orbital plane • A lamp, placed in the middle, represented the sun. • A picture of Polaris was taped on the ceiling toward the North end of the classroom for orientation.	• Students explore movements of the planets and the moon by acting as the objects themselves in the three-dimensional space of the classroom • Able to act out and experiment with the timing of planetary motions and their orientation to the sun allowing exploration of day/night and seasons • Able to act out and experiment with the timing of the motions within sun-moon-Earth system to explore moon phases and eclipses

Tools/Resources	**Examples/Description**	**Uses**
Star Lab® Planetarium	• Portable planetarium set up in the commons area • Multiple display cylinders allow projection of star fields of the Northern and Southern hemispheres along with constellations, the ecliptic and zodiac. • Ability to project moon and planets	• Look at the sky at different times of the day/night, different times of the year, and from different latitudes. • Speed up time to look at star, moon, and planet movements from an Earth-based perspective in a much shorter span of time
Props	• When we were learning about gravity and how it causes orbital motion, I created a "gravity well" demonstrator using a large sheet of spandex stretched over a hoop made with a tent pole. • We also used a globe, a basketball, tennis balls, seeds, marbles, etc.	• In the gravity well, marbles and steel bearings of different weights were used to model how gravity pulls objects towards each other. • When the objects' trajectories were off-center, the lighter object would always orbit the heavier object for at least a short time. • The basketball, globe, tennis balls, seeds, marbles were used to act as scale models of the earth, moon, and sun in different investigations.
Canvas®	• Our district's learning management system	• Organize and share websites, images, and interactives • Create online discussions allowing open-ended questions requiring students to write a thoughtful response. • Limiting students' from seeing other responses before answering allows them to think deeply on their own before participating in a discussion. • New questions and ideas are posted to refer back to at a later time.

Figure 13. Resources and tools used to enhance student understanding.

Scientific Practices

It is unrealistic to think that every NGSS scientific practice is incorporated into every unit, nor should they be. "The overall objective is that students develop both the facility and the inclination to call on these practices, separately or in combination, as needed to support their learning and to demonstrate their understanding of science and engineering" (NRC, 2012). For this reason, I took time to think about which practices I wanted to focus on. I picked ones that fell within the following criteria: The practice had to (a) give the most benefit for the students when used, (b) be the best fit with what was being learned, and (c) be a practice in which I was proficient or one that I wanted to work on to improve my teaching. Using these criteria, the two SEPs specific to this standards bundle were *developing and using models* and *analyzing and interpreting data*.

Developing and using models. Students can use models to help them make sense of complex and often abstract phenomena (Schwarz, Passmore, & Reiser, 2017). The solar system is too vast to study in the lab without the use of models. In this unit, students developed and revised several models that helped them predict and describe different space phenomena. They also revised their models once or twice as they gained a deeper understanding of the phenomena through investigations.

An important aspect of *developing and using models* was how well this SEP integrated with the *constructing explanations* SEP. "The model is the set of ideas that are used in an explanation for some phenomenon, and the explanation is the product of playing out the model in a particular situation to account for that phenomenon" (Schwarz, Passmore, & Reiser, 2017, p. 119). It seemed unrealistic to use one without the other. Students were able to use their models to help them communicate their ideas to others while bringing their current understanding of the phenomenon to light.

Analyzing and interpreting data. "The Analyzing and Interpreting Data practice highlights the act of ascribing meaning to relationships in data, supported by a wide range of tools and processes, including statistics, graphs, visual displays, and other mathematical tools" (Schwarz, Passmore, & Reiser, 2017, p. 161). Using data was an important component to our investigations of several phenomena. For example, we gathered data for average seasonal temperature and the distance of the earth to the sun at different times of the year when we were investigating the cause of seasons. However, it was the interpretation of data that was important for students. They analyzed the relationships of the two data sets and developed conclusions about whether the distance of Earth to the sun could be the cause of seasons.

Instructional Strategies

It is also unrealistic to think that every instructional strategy could be incorporated into every unit. Therefore, I used the same criteria for determining which strategies I would focus on as I did for the SEPs. The teaching strategies I prioritized were *discourse and publicly representing student ideas*, and *using assessment to inform instruction*. I felt that these two would provide the most benefit for students in this particular unit, and each was a practice I wanted to improve on in my teaching

Discourse and publicly representing student ideas. Getting students to talk about their ideas and understanding of the concepts proved to be a critical strategy for this project. To facilitate discussion, I used talk moves such as re-voicing, asking students to explicate their reasoning, and using wait time. These are described in more detail in Figure 14, originally developed by Michaels, Shouse & Schweingruber (2008). I also used questioning prompts outlined in the *Eliciting students' ideas* primer on the *Tools for Ambitious Science Teaching* website (2018) such as "What do you see going on here?," "How do you think this happens?," and "Why do you think it happens this way?" As students talked about their ideas, I recorded those ideas on the board. This validated the students' ideas, allowing them to realize their thinking was important. It also got the ideas out in the open so they could be critiqued by the classroom community. Ideas became community knowledge which could be levied by anyone throughout the course of the unit. Two important considerations I needed to make as I implemented this strategy were: (a) creating an environment where students felt safe to share their claims without personal judgement, and (b) making sure students understood they would be expected to back up their claims with evidence. These expectations were made clear and agreed upon by the class ahead of time.

Talk Move	*Example*
Revoicing	"So let me see if I've got your thinking right. You're saying ________?" (with space for student to follow up)
Asking students to restate someone else's reasoning	"Can you repeat what he just said in your own words?"
Asking students to apply their own reasoning to someone else's reasoning	"Do you agree or disagree and why?"
Prompting students for further participation	"Would someone like to add on?"
Asking students to explicate their reasoning	"Why do you think that?" or "What evidence helped you arrive at that answer?" or "Say more about that."
Using wait time	"Take your time. . . . We'll wait."

Figure 14. Talk Moves described in *Ready, Set, SCIENCE!* (Michaels, Shouse & Schweingruber, 2008).

Using assessment to direct instruction. Research has shown formative assessment to be one of the most important and effective practices to support student learning (Konicek-Moran & Keeley, 2015). Through class discussions, observations of group work, and other formative assessments like Keeley's *Uncovering Student Ideas* probes (Keeley & Sneider, 2012), I was able to get a better idea of what my students knew and understood. I could adapt the lessons based on the needs and interests of the students. I was able to structure the next day's lessons around the students' ideas from the previous day and any alternate conceptions we needed to address. By integrating these informal assessments into our everyday routine, it helped me determine how well students were integrating the concepts into their thinking. Without some form of regular assessment, there was no way for me to know this.

Formal assessments. I assessed my students informally throughout the unit, but I also incorporated five formal assessment projects at strategic points along the way. These included a *Phases of the Moon* summative assessment, a *Planning for the Next Big Eclipse* formative assessment, a *Reasons for the Seasons* formative assessment, a *Movement of Objects in Our Solar System* summative assessment, and a *Scale of Objects in the Solar System* summative assessment. I created rubrics for each of these, which I used for evaluation and feedback. The prompts and rubrics are shown in detail in Appendix E. Finally, I determined criteria to use in tandem with the rubric to determine the percentage-based grades required by my school.

These assessments were quite different from the single comprehensive final written assessment I had given in the past. When looked at critically, the old assessment was simply a test of how well they had memorized disconnected facts. It told me little about how well they understood the concepts and the relationships between those concepts. In contrast, the new assessments gave me a better picture of student understanding and the connections they were making between the concepts and their everyday lives.

Chapter 5 - Piloting the Unit

Introducing the Initial Anchoring Phenomenon

Having an anchoring phenomenon was critical in the success of this unit. It was the backbone of our explanations and it helped to highlight other phenomenon students noticed along the way. It was remarkable how fully engaged my students were throughout the entire unit with an interesting phenomenon to maintain their focus.

On the first day of the unit I introduced the initial phenomenon. Our community was in the path of totality for the *Great American Solar Eclipse* on August 21, 2017. On January 31, 2018, we were able to watch the *Super Blue Blood Moon* lunar eclipse. Because of our location, both of these phenomena were relevant and fresh in the students' minds. I began by showing them images of each eclipse taken from different perspectives. After a short discussion about their experience during each event, I asked them to explain how each type of eclipse happened.

Using their personal experiences and prior knowledge, students could begin to seriously think about the possible causes for each eclipse and share those ideas. This gave me an opportunity to listen carefully for partial understandings and alternate conceptions. I also listened to the language they used and the way they connected to their everyday experiences. This helped me to plan for the unit's next steps.

In our follow-up discussion, we generated questions we would need to answer in order to understand the cause of eclipses. The questions my two classes generated were: (a) What kinds of eclipses are there? (b) What are the sizes of the objects involved? (c) Which objects are involved? (d) What are the positions of the objects during an eclipse? (e) How do the objects move (the mechanism of their movement)? (f) When and where do eclipses happen? (g) How do orbits affect eclipse? and (h) What are the paths the objects follow? From these questions we determined a direction. After some discussion and guiding questions from me, the class agreed to begin with the exploration of how objects travel in our solar system. Students realized they needed to understand how solar system objects moved. However, they were also interested in the cause of those movements, which we would quickly identify as gravity.

Unit Flow - Expectations versus Reality

In order to determine how well this planning paid off, I implemented the unit with my current 8th grade students. This method of teaching puts the students in the driver's seat and therefore the unit can take different paths. Perhaps counterintuitively; teaching the unit was an integral part of the planning. I had already determined the path I thought would make the most sense, but I needed to see how the storyline would morph as it was implemented. Piloting the unit helped me make sure students could meet all the performance expectations no matter what path we took.

Overall, the unit progressed much as I expected. I was glad I had put so much time into my preparation; it proved invaluable when students wanted to take a diversion. Nonetheless, there were still moments that I was not prepared for. This was stressful at first, but I quickly realized that given the right guidance, my students could think through a problem and come up with amazing group explanations. When I learned to put the burden on them, step back, and act as a facilitator, I found they were quite capable of answering their own questions. Sometimes, I had to help them refine their questions, point them in the right direction to find evidence or data, or help them come up with an investigation to test their theories. However, they learned to use these investigations to make their own conclusions. Allowing students to take control of their learning was not something that happened overnight. I struggled for quite a while, wanting to jump in and give them the answers.

My students worked through the storyline in almost the same order I had planned. I would love to think that this is because of my superior understanding of the minds of middle school students. However, I fear it may have been because, at least initially, I guided the process too much. Towards the end of the unit I was getting better about letting the students determine the direction we would go. What follows are some of the interesting and compelling instances that occurred during the unit.

Diversions can lead to deeper understanding. During a discussion on the mechanisms that cause solar eclipses, we were using an eclipse simulator on the interactive whiteboard to test some of the students' ideas. We also used a globe to represent the earth and a baseball to represent the moon in order to kinesthetically model different scenarios in three-dimensional space. By this point, we had reached the consensus that solar eclipses were caused by the moon moving directly between the sun and the earth. However, students were starting to make some other observations and had some new questions.

One student noticed something perplexing. They realized the eclipse shadow from the Great American Eclipse had moved across the earth from West to East. This student pointed out that we had already figured out that the Earth turns toward the East and this meant the shadow should appear to travel from East to West, just like the other objects we see in the sky. I was a bit perplexed myself because I had never really considered this and I wasn't exactly sure of the answer.

Realizing this was a great opportunity for scientific thinking, I challenged the students to figure it out. They were stumped until I restated the question in a way that could be tested. We really needed to find out whether the shadow moved because of the earth's rotation or if it was because of something else. We talked about what the "something else" could be. They decided that since the sun and the moon were the only other objects involved, it had to be one of those. Everyone agreed the sun probably wasn't the cause, because earth moved around it.

After more discussion, the student holding the baseball started moving it around the earth and told the person with the globe to start it spinning. Several students jumped in and corrected the direction of the moon. They remembered, from our previous explorations in the classroom planetarium model and from observations in *Celestia*, that the moon traveled in a counterclockwise direction when viewed from above the North Pole. After this correction, some students started to realize what was going on, but most were still in the dark. However, none were ready to commit to an answer.

They were finally convinced when we brought out our bright lamp to represent the sun and tried it with the lights off. We positioned the moon at the scale distance from the earth (about 24 feet) so the shadow would be the right size. We started by holding the moon still and had someone turn the earth very slowly. As the earth turned, we watched the North American continent move under the shadow. We saw that the shadow started on the East coast and the continent moved under it until the shadow was on the West coast. This was not the way the actual eclipse had moved! Students were convinced it could not be the movement of the earth, but they still wanted to see if the moon's movement would explain it. Next, they took the baseball and orbited it in the correct direction between the "sun" and the "earth". The shadow moved from the West coast to the East coast just like it did in reality. It was because of the moon's movement! This extensive discussion and modeling helped the students understood why the shadow moved from west to east.

This was a completely unplanned exercise; something I never would have thought of on my own. There were several instances like this, where either a student or I noticed something interesting or perplexing. Students were more engaged during these impromptu investigations because they were invested in the outcome. I also noticed that these opportunities helped students review and solidify their understanding of previously covered concepts. This unplanned example was undoubtedly the activity that helped some students understand how the Earth-Moon-Sun system worked.

Formative assessments reveal student thinking. We had just completed the *Phases of the Moon* strand of the storyline, and the students were working in small groups to complete a formative assessment task. The task was based on one of Paige Keeley's prompts (Keeley & Sneider, 2012). Students had to determine which person in the story had a correct explanation of why the moon was crescent shaped (Sara said it was "because the moon had moved into Earth's shadow" and Bill said it was "because they were only seeing part of the lit-up side of the moon"). Student groups created a storyboard for a one to two minute video that used a model to explain who they agreed with and why (see Appendix D).

Every group had determined that Bill had the correct answer and they were productively working to develop their storyboard explanations. However, one of the groups was having a heated argument about how it actually worked. One student was confused about the position of the earth, moon and sun that created the appearance of a crescent-shaped moon from earth. By the time I arrived, the other students were trying to explain it, but they were getting confused as well. The para-professional educator, who was in my room and had come over to help, admitted that she was confused, too.

In the past, I probably would have given them a detailed explanation of the concept. However, what I did instead made all the difference. Rather than attempt to explain, I said, "Let's go over to the lab and figure it out." They used the lamp and Styrofoam balls from earlier investigations and the simulations on their computers. They worked together to figure out how to make the moon appear to have a crescent shape from Earth's perspective. Within about five minutes, they had it figured out and were excited to explain it to me. I suggested they try several other phase shapes to make sure they truly understood it. After a few more minutes with the model, they were pretty sure they had it.

As a final check, I had them explain it to the para-professional while I listened in. They did a great job and it was clear they understood it well. However, even though they were explaining it clearly, she still did not understand. She was essentially in the same place they had been 15 minutes prior. To remedy this, I had the group of students take her to the lab to try it out herself. I tagged along to see what would happen. They helped her use the model, which she had not done previously. Suddenly, I saw the realization hit her! In this case, both she and the students needed to use the kinesthetic models before they had the "aha!" moment.

I was able to use this formative assessment the way these assessments are meant to be used; as a way to determine gaps and to help them change their thinking before moving on. Had I waited until the end of the unit, it would have been too late to do anything about it. This was a chance for my students (and me) to check their understanding and clear up misconceptions that still existed.

Focus on the concepts, the vocabulary will follow. I made it a point to avoid formal vocabulary study. While vocabulary is critical to effective communication, I have found the typical activities that I have used previously to have students "memorize" vocabulary are often ineffective. Rather than completing vocabulary lists, worksheets, and Quizlets, we just focused on investigating the phenomena. During discussions, students used whatever words made sense to them. As a talk move (Michaels, Shouse & Schweingrube, 2008), I often restated what students said, but I made sure to mix in the correct vocabulary. Students began to replace their own vocabulary with correct scientific vocabulary over time.

Students used word like “spin” in place of “rotation” and “go around” instead of revolution. While this was not scientific vocabulary, we could still share ideas and clearly understand each other. However, students quickly started to replace this everyday vocabulary with scientific vocabulary as they learned more about the phenomenon. Words like rotation and revolution started appearing regularly in their responses. This was surprising to me because past students have consistently mixed up those terms. It turned out that just using the terms in our conversations was more effective than my efforts to make them memorize them.

Another example occurred as we investigated the phenomenon of the changing shape of the moon. Traditionally, teachers have students memorize the names of eight moon phases. However, I realized this vocabulary was completely unnecessary to understand the mechanisms that caused the moon’s changing appearance. I decided not to focus on the terms so we could focus our effort on the investigations. As it turned out, the students wanted to know the terms even though I did not emphasize them. Once they understood the mechanism, the vocabulary became of interest to them.

This reinforced my feeling that vocabulary is secondary to conceptual understanding. Since I worked to place my focus on the conceptual understanding of scientific phenomenon, it meant everything we did in class had to lead to that understanding. Thus, vocabulary was introduced only as it became necessary to accomplish our goals. In spite of this lack of focus, students picked up the vocabulary and correctly used it once they had a solid understanding of the phenomenon or concept.

Using models to expose evidence for claims. One day, we were trying to determine exactly how the moon and earth moved in relation to each other. We had watched a time-lapse video of the moon over the course of a month as seen from Earth. Students noticed that the amount of the moon that was lit up appeared to be changing and that the same side of the moon could be seen at all times. Students were also already aware that the moon revolved around the earth in a circular path.

I asked them whether the moon rotated on its axis as well. Some were convinced that it did, others were not. I asked each side to present their evidence. One had her friend act as the earth while she acted as the moon. She walked around the “earth” facing him the whole time in the way one side of the moon faces the earth all the time. After completing one revolution, she pointed out that she had faced every wall in the room as she revolved.

I had them do it again, having the “moon” stop every quarter of the way while pointing out the direction the she was facing at each stop. This convinced all but two students. Needing to come to a consensus, I asked if anyone could figure out a way to convince the others. What finally convinced them was when one student revolved as the moon while another student standing off to the side faced the same direction as the moon as it revolved. The person standing in one spot ended up rotating exactly one time during the revolution.

The students all learned a valuable lesson about scientific claims and the requisite evidence that must go along with it to convince others. It was frustrating and it took encouragement and guidance from me, but it was worth it. The process of making claims and backing them up with evidence became a class expectation that students grew more comfortable with it as the unit progressed.

The Experience

It is clear that the learning was constantly evolving through the course of the unit. Each of my classes had slightly different experiences as they journeyed through the storyline. Yet, every student received the same essential understandings that I had determined ahead of time. Different paths were followed and diversions were taken as the needs and interests of students dictated. The other science teacher's classes took a different route through the unit than my classes, but all students learned the same concepts. That is the beauty of this method of teaching; with proper preparation and flexibility, teachers can provide experiences for students to learn in a way that is interesting to them while still ensuring a deep understanding of critical concepts.

Since this unit was at the end of the school year, I was concerned my students would have trouble staying on task. Surprisingly, my students were more engaged during this unit than they had been in any of the prior ones. The phenomenon-based learning seemed to draw them into it. Every student, including my most reluctant learners, actively participated in the work. It was almost as if they couldn't help themselves. Adults who visited my classroom noticed and made comments on the level of student engagement as well. I still had some students who were uncomfortable talking in whole-class discussion, but they found their voice in their small groups and online discussions. Not every day was perfect. Some students came in with bad attitudes, but they inevitably ended up getting involved. I think they were excited to participate in authentic science and to not have information thrown at them. I am convinced I need to continue working to create this environment for all of my units. It is clear that it makes a large difference in students' deep understanding of important scientific concepts and their overall enjoyment of learning.

Chapter 6 - Discussion

Lessons Learned

I set out to answer the following questions: (a) What can be learned about the process of developing an eighth grade Earth and Space Science phenomenon-based storyline unit using all three dimensions of the Next Generation Science Standards by a practicing teacher? (b) How can the lessons learned from the development of this unit help others to do similar work? and (c) What are the benefits and challenges related to this process of unit development? Through the development of the unit and piloting it with my classes, I was able to answer each of these questions. I learned many valuable lessons as I worked on this project. It has fundamentally changed the way I think about teaching science. Although there were significant challenges along the way, the benefits far outweighed them. I hope others will be able to use this documentation to give them ideas and inspire them to make similar changes in their teaching.

The benefits of phenomenon-based, student driven learning are innumerable. As noted earlier, student engagement was much higher than it had been during any of my other units. Students were eager and capable to drive their own learning. They often came to class talking about what we had done the previous day and asking questions that they had thought of that night. Because of their direct involvement in their learning, their understanding of the essential concepts was greater as well. The products they created showed a much higher level of understanding than what I had seen in my previous students.

The design and implementation of this unit was an eye-opening experience for me. I learned a lot about my teaching strategies and myself. Specifically, I realized I was capable of making the changes necessary for middle school students to learn science more effectively. I was able to see the difference this made in my students' enjoyment and conceptual understanding compared to my more traditional teaching practices.

The preparation for this unit was a huge undertaking. I worked on it for over six months while teaching. What I realized when I implemented the unit was that all my effort had been worth it. The actual teaching of the unit ended up requiring little extra preparation and was, for the most part, stress-free. The students really did most of the work and my role was as a facilitator of discussion and provider of occasional guidance.

This was as much a learning process for me as it was for my students. Much of the development time this unit required was due to the conceptual changes I needed to make myself. I had a lot to learn before I could implement a unit that took full advantage of the NGSS and the best practices that go along with them. I think this will get easier in the future as I gain experience and increase my understanding of the process. In fact, the storyline unit that I am currently developing is going much faster because of what I learned from this one.

Another lesson learned was that even though the students drove the learning, I still had to be the instructor. I kept the lessons from getting off track by using questioning strategies and redirections as needed. A lot of this entailed helping my students be interested in the concepts they needed to learn about. Reiser (2017) points out that we want students to have a goal that emerges from something they are interested in, but we need to help them to be interested in that topic. "We might have to contrive it because we can't just let them go wherever they want" (Reiser, 2017, 7:52). In other words, we have to take the reins from time to time, but ultimately the students' curiosity should drive the lessons. We just might have help them find that curiosity.

The biggest epiphany I had was realizing the colossal change you can foster in your classroom by just implementing two specific teaching practices (along with the appropriate strategies). As a reminder, the ones I used were having students develop models and use those models to construct explanations of important science concepts. This was a combination of two

SEPs, but it seems unlikely one would be used without the other. The second was game changing; having students share their thinking with each other. This discourse was critical for helping the speaker and the listener formulate their conceptualization of the big ideas. It allowed others to hear differing perspective and critique those ideas against their own and the evidence that had been presented.

Ultimately, I did not allow enough time for the unit. This will be something I need to consider in my future plans. I taught this unit at the end of the school year, so I was limited to just six weeks. As can be seen by the calendar I kept (Appendix F), I didn't have time to properly complete the last two lessons and I was not able to pilot two of my assessment prompts. I plan to partially alleviate this problem by integrating this unit into my *Forces and Interactions* unit. A lot of what we learned in the early part of this unit could easily cover some of the NGSS performance expectations in the forces unit. I also have a better understanding of just how long we need to spend on each concept. This may still vary slightly from class to class but I realize I have to give myself that flexibility.

Recommendations

This project was extremely beneficial to both myself as an educator and to my students. It would be well worth the time of any teacher. Creating an environment where every student, regardless of ability, can engage in authentic science has had more impact on student learning than anything else I have tried. However, there are some important recommendations that can make the process easier.

A teacher wanting start this process should probably start with a unit they already teach. The first attempt will take a long time and require a great deal of effort. Starting with a unit they are comfortable with will make the process easier. After completing one unit, it becomes easier to start working on other units. Realistically, it will probably take several years to completely transform their curriculum.

Teachers can begin by taking a fresh look at the standards for their class and considering how they might be bundled. They may find that they can incorporate other connected standards. Next, as Reiser (2017) suggests, they should look at their current lessons and consider how those can be changed to put the students in the position of the scientist rather than just doing activities because they were told to. Teachers to need consider ways their lessons can provide opportunities for students to ask questions and think of ways to answer them.

I would recommend writing a gapless explanation of critical concepts (Windschitl, Thompson & Braaten, 2018). This proved to be one of the most beneficial activities I did. It allowed me to identify holes in my own understanding, and I researched concepts I was not completely comfortable with. Writing my explanation also allowed me to collect my thoughts and make sure I completely understood all aspects of the performance expectations. I began to consider ways to incorporate applicable SEPs, CCCs, and DCIs as well. This process increased my comfort level and it proved invaluable while planning the unit.

It is important to remember that the teacher must remain flexible with both the slight diversions that will take place and the time the unit might take. Students who are engaged in the investigation of a phenomenon will ask a lot of questions and are will develop many different ideas about how to answer those questions. The teacher has to help to guide these questions and ideas into a meaningful experience for all students.

Finally, I realized that I did not need to throw out all of my demonstrations, labs, and textbook readings. They were useful tools at times during the unit, and I found occasions where they helped to provide information or to show students something that would have been impractical for them to come up with themselves. This was a major overhaul to the way I have taught in the past, but I still had a lot of great lessons and activities I was able to use. Some just took more modification than others.

It is important to continue fine-tuning the unit to make improvements. The scope of this project only allowed for documentation of the process of designing and implementing the unit. Future research could be done to make a detailed analysis comparing student performance from my traditional unit to student performance within this newly developed unit. Further studies could also include: looking at the effect of phenomenon-based learning on student engagement, determining how this type of learning affects the permanence of conceptual understanding into future school years and later life, considering whether it leads to improvement in performance in future science classes, and finding out if it has an impact on the number of students moving into STEM fields in college and future careers.

Conclusion

While the NGSS set ambitious goals, I found those goals to be well worth the effort it took to reach them. It required a significant amount of persistence and grit from both me and my students. Nonetheless, the deep understanding that resulted should be the goal of any science teacher. The vision set forth in *The Framework* will take time and effort to realize. In documenting my journey through this process, I hoped to show others that fully implementing the NGSS is a task that can be accomplished by a working teacher and it will be worth their time.

The use of phenomena to tap into the innate curiosity of students clearly motivates students to learn. As teachers implement SEPs, CCCs, and DCIs into every aspect of their science classrooms, students will begin to take on the role of scientists, and be in charge of their own sense-making. Children's desire to understand their world is an invaluable tool that teachers can use to make their curriculum compelling and enriching. Students who are learning because they are genuinely invested in the outcome of that learning will retain more, but more importantly, they will gain the skills needed to be lifelong learners, collaborators, and problem-solvers. These are the skills students will need to be successful in a fast-paced constantly changing world.

It is clear to me that this work has fundamentally changed the way I think about teaching science. My teacher education classes, and those of most teachers, did not prepare me to teach in this way. Up until now, I taught traditionally because that was how I was taught in school. However, I have realized in executing this project that my personal learning experience could have been better. This project has put in motion a complete shift in my thinking about teaching. The student experience is everything. It is my job to make that experience as enjoyable and fulfilling as possible. I can do this by introducing interesting phenomenon and making my classroom a place where students are able to engage in authentic science to answer their questions about the world.

References

American Association for the Advancement of Science [AAAS]. (1993, 2009). *Benchmarks for science literacy.* Project 2061. Retrieved from http://www.project2061.org/publications/bsl/online/index.php

AAAS. (1989). *Science for all Americans: A Project 2061 report on literacy goals in science, mathematics, and technology*. Washington, DC: AAAS.

Bailey, M. B. & Slater, T. F. (2003, Jan). A review of astronomy education research. *The Astronomy Education Review, 2*(2), 20-45.

Bakas, C. & Mikropoulos, T. (2003). Design of virtual environments for the comprehension of planetary phenomena based on students' ideas. *International Journal of Science Education, 25*(8), 949-967. doi:10.1080/09500690305027

Brooks, J. G., & Brooks, M. G. (1999). *In search of understanding: The case for constructivist classrooms (revised edition)*. Upper Saddle River, N.J: Merrill/Prentice Hall.

Bundling the NGSS. (2016, June). Retrieved from https://www.nextgenscience.org/resources/bundling-ngss

Falk, B. & Blumenreich, M. (2005). *The Power of questions: A guide to teacher and student research.* Heinemann: Portsmith, NH.

Ferrance, E. (2000). *Action research*. LAB, Northeast and Island Regional Education Laboratory at Brown University. Retrieved from https://www.brown.edu/academics/education-alliance/sites/brown.edu.academics.education-alliance/files/publications/act_research.pdf

French, D. A., & Burrows, A. C. (2017, March-April). Inquiring astronomy: Incorporating student-centered pedagogical techniques in an introductory college science course. *Journal of College Science Teaching*, *46*(4), 24.

Houseal, A. (2015). A visual representation of three dimensional learning: A tool for evaluating curriculum. *Science Scope, 39*(1), 58-62.

Hunt, T. C. (2016). National Defense Education Act (NDEA). In *Encyclopaedia Britannica Online*. Retrieved from https://www.britannica.com/topic/National-Defense-Education-Act

Keeley, P., & Sneider, C. I. (2012). *Uncovering student ideas in astronomy: 45 formative assessment probes*. Arlington, VA: NSTA Press.

Konicek-Moran, R., & Keeley, P. (2015). *Teaching for conceptual understanding in science*. Arlington, VA: NSTA Press.

Krajcik, J., Codere, S., Dahsah, C., Bayer, R., & Mun, K. (2014). Planning instruction to meet the intent of the next generation science standards. *Journal of Science Teacher Education, 25*(2), 157-175. doi:http://dx.doi.org.libproxy.uwyo.edu/10.1007/s10972-014-9383-2

Kuhn, T. S. (1962). *The structure of scientific revolutions*. Chicago, IL: University of Chicago Press.

Michaels, S., Shouse, A.W. & Schweingruber, H. A. (2008). *Ready, set, science!: Putting research to work in K-8 science classrooms.* Washington, DC: The National Academies Press.

Morrow, C. A. (2000). Kinesthetic astronomy: The sky time lesson. *The Physics Teacher*, *38*(4), 252-253.

National Commission on Excellence in Education. (1983). *A nation at risk: The imperative for educational reform.* Washington, DC: National Commission on Excellence in Education.

National Research Council [NRC]. (1996). *National science education standards*. Washington, DC: The National Academies Press.

NRC. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Quinn, H., Schweingruber, H., & Keller, T. (Eds.). Washington, DC: The National Academies Press.

NRC. (2015). *Guide to Implementing the Next Generation Science Standards*. Washington, DC: National Academies Press. Retrieved from http://www.nap.edu/catalog/18802/guide-to-implementing-the-next-generation-science-standards

Next Generation Science Storylines. (2017). Retrieved from http://www.nextgenstorylines.org/

NGSS Lead States. (2013). *Next generation science standards: For states, by states.* Washington, DC: The National Academies Press.

Pruitt, S. L. (2014). The next generation science standards: The features and challenges. *Journal of Science Teacher Education, 25*(2), 145-156. doi:http://dx.doi.org.libproxy.uwyo.edu/10.1007/s10972-014-9385-0

Radinsky, J., Oliva, S., & Alamar, K. (2010). Camila, the earth, and the sun: Constructing an idea as shared intellectual property. *Journal of Research in Science Teaching, 47*(6). 619–642. doi:10.1002/tea.20354

Ravitch, D. (1990). Education in the 1980's: A concern for 'quality'. *Education Week, 9*(16). 48.

Reiser, B. [Michigan Math & Science Centers Network]. (2017, April 26). *Brian Reiser: Current storylines to support 3-D learning* [Video File]. Retrieved from https://www.youtube.com/watch?v=CkUED-6jPOM

Richland, L. E. & Simms, N. (2015). Analogy, higher order thinking, and education. *Wiley Interdisciplinary Reviews Cognitive Science, 6*(2). 177–192. doi:10.1002/wcs.1336

Sagor, R. (2000). *Guiding school improvement with action research.* Alexandria, VA: ASCD.

Schneps, M. P. (1989) *A Private Universe* [Video]. San Francisco: Astronomical Society of the Pacific.

Schwarz, C. V., Passmore C., & Reiser, B. J. (2017). *Helping students make sense of the world using next generation science and engineering practices*. Arlinton, VA: NSTA Press.

Slater, T. F., & Gelderman, R. (2017). Addressing students' misconceptions about eclipses. *The Physics Teacher, 55*(5), 314-315. doi: 10.1119/1.4981046

Smith, J. P., & Girod, M. (2003). John Dewey & phsycologizing the subject matter: Big ideas, ambitious teaching, and teacher education. *Teacher and Teacher Education*. *19*, 295-307. doi 10.1016/S0742-051X(03)00016-7

Stroupe, D. (2014). Examining classroom science practice communities: How teachers and students negotiate epistemic agency and learn science-as-practice. *Science Education. 98*(3).487–516. doi:10.1002/sce.21112

Stroupe, D. (2017). Ambitious teachers' design and use of classrooms as a place of science. *Science Education. 101*(3), 458–485. doi:10.1002/sce.21273

Trumper, R. (2001). A cross-age study of junior high school students' conceptions of basic astronomy concepts. *International Journal of Science Education, 23*(11), 1111-1123. doi: 10.1080/09500690010025085

Trumper, R. (2006). Teaching future teachers basic astronomy concepts—seasonal changes—at a time of reform in science education. *Journal of Research in Science Teaching, 43*(9), 879-906. doi: 10.1002/tea.20138

Turley, R., Trotochaud, A., & Campbell, T. (2016, September 1). Achieving liftoff: using coherent storylines to explain phenomena. *The Science Teacher, 83*(6), 35-41.

Windschitl, M., Thompson, J. & Braaten, M. (2018). Tools for Ambitious Science Teaching. Retrieved from https://ambitiousscienceteaching.org/

Windschitl, M., Thompson, J., Braaten, M., & Stroupe, D. (2012). Proposing a core set of instructional practices and tools for teachers of science. *Science Education, 96*(5). 878–903. doi:10.1002/sce.21027

Wiggins, G. P., & McTighe, J. (1998). *Understanding by design*. Alexandria, Va: Association for Supervision and Curriculum Development.

Appendix A – Daily Reflection Form

Date:	Lesson #:	Prep Time:

What was my process for today?

	Student	Teacher
Benefits (ex: depth of understanding was higher, level of engagement was higher, lesson was easily implemented, lesson was successful, etc.)		
Challenges (ex: material was too difficult or too simple, some students weren't able to participate, something came up that I wasn't expecting, development or implementation took too much time, etc.)		

How difficult was the process today? 1 2 3 4 5

What was my level of satisfaction with today's lesson? 1 2 3 4 5

What was the level of student engagement? 1 2 3 4 5

What questions came up? Where do we go from here?

How could I improve this lesson?

Appendix B – Anticipated Questions

Strand	Anticipated Questions
Eclipse	If the moon does not make its own light where does its light come from?
Eclipse	What causes each type of eclipse?
Eclipse	Why don't eclipses happen every month?
Eclipse	Why do eclipses happen in different places on Earth?
Eclipse	Can other objects cause eclipses? like Mercury, Venus, Mars
Eclipse	Why do solar eclipses only occur during a new moon?
Eclipse	Why do lunar eclipses only occur during a full moon?
Gravity/Inertia	Why do planets, etc. keep orbiting the sun instead of flying off into space?
Gravity/Inertia	Could Earth ever capture a second moon?
Gravity/Inertia	Why don't asteroids clump into planets?
Gravity/Inertia	Why are planets round?
Gravity/Inertia	How is gravity different on different planets, etc.
Gravity/Inertia	How do moons not crash into planets?
Gravity/Inertia	How do planets stay in their orbit without moving closer/farther from the sun?
Rotation/Rev.	Why do we see different constellations at different times of the year/night?
Rotation/Rev.	Why are there moon phases?
Rotation/Rev.	Why do stars "appear" to move from east to west throughout the night?
Rotation/Rev.	Why do constellations seem to move as the seasons change?
Rotation/Rev.	Why do the planets appear to move through the zodiac from night to night?
Rotation/Rev.	How does the earth move?
Rotation/Rev.	How do we measure the rotation and revolution of the earth?
Scale	How far away are the moon, sun, and other solar system objects?
Scale	How do the sizes of other objects in the solar system compare with Earth?
Seasons	Do all planets spin on an axis like Earth?
Seasons	What causes the seasons on Earth?
Seasons	Why is it so cold at the polar regions and hot at the equator?
Seasons	Why is it warmer in the summer and colder in the winter?
Seasons	Why is the day longer in the summer and shorter in the winter?
Seasons	Why does the sun/moon seem to be higher in the sky during the summer than the winter?
Seasons	How are seasons different at the equator compared to Wyoming or the north pole
Seasons	What would happen if Earth's axis was not tilted?
Seasons	Does the north pole point in different directions through the year?
Seasons	Why are seasons opposite in the northern and southern hemisphere?
Solar System	Is the sun moving also?
Solar System	What is our solar system's place in the galaxy?
Solar System	What does our solar system consist of?
Solar System	Do the all the planets orbit in the same plane?

Appendix C – Storyline Skeleton

Space Systems Unit - Storyline Skeleton

Lesson Routine	Questions	Phenomena / Problems	What we figured out
AP Anchoring Phenomena		Solar and Lunar Eclipses	We generated a lot of questions: What kinds of eclipses are there? What are the sizes of the objects involved? Which objects are involved? What are the positions of the objects during an eclipse? How do the objects move? When and where do eclipses happen? How do orbits affect eclipses? What is the path the objects follow?
L1 Investigation	What is the role of gravity in the motions of objects like planets, moons, asteroids and comets within our solar system?	Orbital Motion	Orbital motions within our solar system are caused by the interactions of those objects' centrifugal force (caused by their angular momentum) and the gravitational force between them and a central body.
L2 Putting the Pieces Together	How do different objects like planets, moons, asteroids and comets actually move within our solar system?	Orbital Motion	All objects in our solar system move in orbits around other bodies in the system. Planets and most asteroids orbit the sun in nearly circular or slightly elliptical orbits in the same plane. Moons orbit planets but not always in this same plane. Other objects like dwarf planets and comets often have very elliptical orbits.
L3 Investigation	What patterns of the apparent movement of objects across the sky can be observed from Earth?	Cyclic Patterns of Night Sky Objects	The objects we see in space from the earth's surface appear to move in predictable and cyclic patterns. Objects like the moon, the sun, and most of the stars all appear to move across the sky from East to West. However, stars in the Northern sky appear to move in a counter-clockwise circle around a single star named Polaris.
L4 Investigation	How do the movements of these objects look different from space than they do from Earth?	Cyclic Patterns of Night Sky Objects	To us on Earth, it appears that the moon, stars and sun move all the way across the sky in one night/day, but when viewed from space, we could see that they actually moved very little over that period. We also noticed the Earth rotates (and us along with it) all the way around in a 24 hour period.

Lesson	Question	Topic	What we figured out
L5 Putting the Pieces Together	What is it about the Earth-Moon-Sun System that causes us to see objects travel across our day and night sky in predictable patterns?	Cyclic Patterns of Night Sky Objects	The movement of objects we see from Earth seems to be caused by the Earth's movement and not the movement of the objects. For example it appears that the moon moves across the sky in one night, but when viewed from space, we could see that it moves very little over one night. However the Earth rotates nearly half way around over that night.
L6 Investigation	What initial observations can we make about the moon to help understand why we see it the way we do from Earth?	The Moon's Changing Shape	We noticed that over the course of 28 nights, the moon goes through a predictable and repeating pattern of "shapes". We saw that the same side of the moon was always facing us no matter what shape it was and that if you looked close enough you could still see the whole moon. Just part of it was lit up. We also observed that the light came from the sun.
L7 Investigation	What is it about the Earth-Moon System that causes us to see the moon rise and set at different times throughout the year?	The Moon's Changing Shape	The moon is orbiting the earth once every 28 days and each night we see it from earth in a different part of its orbit. This makes it appear to rise and set at different times throughout the month. It doesn't just show up at night. We often see it during the day as well.
L8 Putting the Pieces Together	What is it about the Earth-Moon-Sun System that causes us to see different parts of the moon at different times of the month?	The Moon's Changing Shape	One half of the moon is always lit by the sun. However, as it revolves around the earth, we are able to see it from different perspectives during the night throughout the month and this causes the phases that we see. The moon's relative position to the sun and the earth allows us to see different amounts of the lit half of the moon as the month progresses.

L9 Investigation; Putting the Pieces Together	What is it about the Earth-Moon-Sun System that causes us to have solar eclipses?	The Great American Solar Eclipse	Because the moon is orbiting around the earth, there are occasions when it moves between the sun and earth causing a shadow over a small portion of the earth's surface blocking the sun for those people in that small area. This shadow sweeps across the earth as the moon moves by. The sun's diameter is approximately 400 times larger than the moon's diameter, but because it is about 400 times farther away from Earth, they both appear to be approximately the same size as viewed from Earth. This allows the moon to just barely cover the sun during a solar eclipse causing the path where the eclipse is visible to be so narrow.
L10 Investigation; Putting the Pieces Together	What is it about the Earth-Moon-Sun System that causes us to have lunar eclipses?	The Super Blue Blood Moon Lunar Eclipse	During a lunar eclipse, the moon travels through the shadow of the earth, which blocks the light from the sun from reaching the moon's surface. During full lunar eclipses, the moon will appear red due to the refraction of light through the edges of Earth's atmosphere. Because the earth is so much bigger than the moon, lunar eclipses last longer and can be seen from a larger area of Earth.
L11 Investigation	Is the distance of the earth to the sun a factor that causes us to have seasons?	Seasons	The distance of the earth to the sun does change slightly, however it does not correlate at all with the seasons. It is currently closer to the sun during our winter and farther during our summer in the northern hemisphere.
L12 Investigation; Putting the Pieces Together	If the seasons aren't caused by the distance of the earth to the sun, what is it about the Earth-Sun System that causes us to have seasons?	Seasons	Seasons are caused by the relative tilt of the earth in comparison to the sun. This tilt stays the same all the time, but that causes different parts of the earth to receive different amounts of sunlight (both time and intensity) as it progresses around the sun. Thus, during different parts of the year, different parts of the earth are warmer or cooler than other parts causing seasons.
L13 Investigation	How can we create a scale model to compare the distances between the objects in the Earth-Moon system?	Scale of the Solar System	It is surprising how far away the moon actually is from the earth compared to satellites, the ISS, and the Hubble telescope. It actually took astronauts a lot longer than we thought to get to the moon.

L14

Investigation

How can we create a scale model to compare the distances between objects in our solar system?

Scale of the Solar System

There is an incredible change in distance from the sun to the inner four planets compared to the outer four planets. There is an even greater amount of distance for Kuiper belt objects and Oort cloud objects. It is difficult to make a scale model of the solar system without reducing the scale extremely.

L15

Putting the Pieces Together

How can we create a scale model to compare the distances between, size of, and physical characteristic of objects in our solar system?

Scale of the Solar System

These distances and the sizes of the planets can be modeled to scale here on Earth. However, it is extremely difficult (nearly impossible) to show the relative distances to scale at the same time as showing the object sizes to scale. It is even more impossible to show the physical characteristics of the planets at the same time.

Appendix D – Teacher Guides

To request the teacher guides that were created for this unit,

please email the author at rruckman59@yahoo.com

Appendix E – Assessment Prompts

Phases of the Moon: Formative (After Lesson 8)

Prompt: Bill and Sarah are looking up into the sky one night and they notice the moon is a crescent shape. They come back out two hours later and the moon is still the same crescent shape but it is a little higher in the sky now. Sarah says that this is because the Moon has moved into the Earth's shadow. Bill disagrees with her. He thinks that it is because they are only seeing a part of the lit up side of the moon. Who do you agree with? Why? Create a storyboard for a 1-2 minute video that uses a model to explain who you agree with and why.
Your explanation must use a model that shows the patterns involved and includes each of the key aspects of the sun-earth-moon system related to phases of the moon.

Rubric for Phases of the Moon	
4	Explanation uses a model, includes each of the 4 key aspects of moon phases, and shows an application of the ideas in a different situation or gives a deeper explanation of underlying mechanisms. For example: ● Comparison to phases of Earth as seen from the moon ● Comparison to phases on other planets as seen from earth ● Explanation of the correlation of phases with eclipses
3	Explanation uses a model that shows the patterns involved and includes each of the following key aspects of the sun-earth-moon system as related to phases of the moon: ● One half of the moon is always lit by the sun. ● As the moon revolves around the earth, the moon's relative position to the sun and the earth allows us to see different amounts of the lit half of the moon as the month progresses. ● The pattern of the phases is cyclic and predictable. ● The procession of moon phases repeats approximately every 29.5 days because of the time it takes the moon to make one full revolution around the earth relative to the sun.
2	Explanation uses a model and includes 2 of the 4 key aspects.
1	Explanation is based on common misconceptions

Develop and use a model of the earth-sun-moon system to describe the cyclic patterns of the phases of the moon.

Key: Blue - SEPs Green - CCCs Orange - DCIs

Planning for the Next Big Eclipse: Formative (After Lesson 10)

Prompt: You have just landed a new job as a travel agent and you want to make a good impression to your boss. You realize that, since the Great American Eclipse, people have become very interested in traveling to places where they can get the best views of eclipses. You decide to make a brochure or an advertisement to explain to people how to be in the right place at the right time. Your brochure will need to have the following:

- Advice on when and where the best place will be to see both the next solar eclipse and the next lunar eclipse
- An easy to understand explanation using a model of how each type of eclipse works

  Tell which type of eclipse is more rare (people will be more interested in it if its rare)
- Explain why it will be very important to be in just the right place for the solar eclipse, but it really will not matter too much for the lunar eclipse

Rubric for Planning for the Next Big Eclipse	
4	Explanation uses a model, includes each of the 4 key aspects of eclipses, and shows an application of the ideas in a different situation or gives a deeper explanation of underlying mechanisms. For example: • Comparison of eclipses caused by other objects such as inner planets or spacecraft. • Comparison of lunar or solar eclipses as observed on other planets. • Inclusion of angle of inclination or elliptical orbit of the moon in explanation.
3	Explanation uses a model and includes each of the following key aspects of the sun-earth-moon system as related to eclipses: • Both lunar and solar eclipses are caused by specific arrangements of the earth, moon, and sun. • During solar eclipses, the moon moves between the sun and the earth and causes a shadow over a small portion of the earth's surface while blocking the sun for those people in that small area. This shadow sweeps across the earth as the moon moves by. • The sun and the moon both appear to be approximately the same size when viewed from Earth. This allows the moon to just barely cover the sun during a solar eclipse. This is why the path where the eclipse is visible on Earth is so narrow. • During a lunar eclipse, the moon travels through the shadow of the earth, which blocks the light from the sun from reaching the moon's surface and reflecting back to Earth.
2	Explanation uses a model and includes 2 of the 4 key aspects.
1	Explanation is based on common misconceptions

Develop and use a model of the earth-sun-moon system to describe the cyclic patterns of solar and lunar eclipses.

Key: Blue - SEPs Green - CCCs Orange – DCIs

The Reasons for the Seasons: Formative (After Lesson 12)

Prompt: I am so tired of having to re-explain to other adults why we have seasons on Earth! It seems like there are so many that just do not get it scientifically! Please help me out, and create a 1-2 minute public service announcement (PSA) that explains the real reason we have seasons. Use models and evidence to convince these adults how it really works.

Rubric for The Reasons for the Seasons	
4	Explanation uses a model, includes each of the 5 key aspects of seasons, and shows an application of the ideas in a different situation or gives a deeper explanation of underlying mechanisms. For example: ● mechanisms -- gravity, angular momentum ● extend to how the earth ended up tilted ● how it compares to other planets like Mars, Uranus
3	Explanation uses a model and includes each of the following 5 key aspects of the sun-earth system as related to seasons: ● The tilt of axis of the earth ● The effect of the angle of sunlight on the heating of the earth at different places and at different times of the year ● The duration of daylight at different places and at different times of the year ● The Earth's perihelion & aphelion and their lack of effect on the seasons ● Describe the pattern of seasons and how they are caused by the revolution and rotation of the earth
2	Explanation uses a model and includes 3 of the 5 key aspects.
1	Explanation is based on common misconceptions

Develop and use a model of the earth-sun-moon system to describe the cyclic patterns of seasons.

Key: Blue - SEPs Green - CCCs Orange - DCIs

Movement of Objects in Our Solar System: Summative (After Lesson 12 & Seasons Formative)

Prompt: The internet trolls are at it again! There is a group who call themselves The Geocentrists who are making posts about how all the objects in our solar system actually revolve around the Earth instead of the sun. It all started as a joke but, unfortunately, hundreds of thousands of people are starting to believe them.
We need to get the correct information out there. Your job is to use what you have learned about gravity, the changing positions of objects in our sky (sun, moon, and stars), moon phases, eclipses, and seasons to create and argument that demonstrates that they are wrong. Create a 2-3 minute video (or write an extensive Facebook post) that shows why the Earth cannot be the center of our solar system. You MUST use models and graphics to make your claims clear. Present as much evidence as you can in 2-3 minutes.

Rubric for Movement of Objects in Our Solar System	
4	Explanation uses a model, includes each of the 5 key aspects of sun-earth-moon system, and shows an application of the ideas in a different situation or gives a deeper explanation of underlying mechanisms. For example: ● Eccentricity of orbits are considered. ● Greater detail of mechanisms than is expected at this grade level is given.
3	Explanation uses a model and includes each of the following key aspects of the sun-earth-moon system to provide evidence that the sun is the center of the solar system: ● The earth, other planets, dwarf planets, asteroids, comets, and Oort Cloud objects all revolve around the sun because of the interaction of the sun's gravity on those objects and the inertia of each of those objects. ● Moons revolve around planets because of the planet's gravity and the moons' inertia. ● All of the movements of objects in the solar system are cyclic and predictable if their correct movement is understood. ● The apparent movement of the sun, moon, planets, and constellations from east to west across the sky is caused by the rotation of the earth. ● The shift of different visible nighttime constellations throughout the year is caused by the progression of the earth around the sun and its relative position to the sun throughout the year.
2	Explanation uses a model and includes 3 of the 5 key aspects.
1	Explanation is based on common misconceptions

1. Develop and use a model of the earth-sun-moon system to describe the cyclic patterns with which objects appear to travel across the day and night sky.
2. Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.

Key: Blue - SEPs Green - CCCs Orange - DCIs

Scale Properties of Objects in the Solar System: Summative (After Lesson 15)

Prompt: Work with your partner(s) to create your own scale model to represent our solar system. You must come to a consensus on how you will create your model. Your model also needs to include an explanation of your choices.

- Be sure that all eight planets and the sun are represented in your model. You may include dwarf planets also if you would like.
- Use actual data and ratios to calculate the scaled distances or sizes of all the objects and use these calculations to create your model as accurately as possible.
- On your model, label each of the objects and include the actual numbers for whatever factor(s) you decided to scale (size, distance, atmosphere depth, etc.).
- In your explanation, describe your process and include the following:
    - Evaluate the strengths and limitations of this scale model compared to the large one we used in class.
    - Are you able to show both size and distance in the same model? Why or why not?

Rubric for Scale Properties of Objects in the Solar System	
4	Explanation uses a model, includes each of the 5 key aspects of solar system, and shows an application of the ideas in a different situation or gives a deeper explanation of underlying mechanisms. ● Explain why even though objects in our solar system are very large in size, they appear very small because of their huge distance from Earth. ● Include other objects in the model (dwarf planets, asteroids, Oort cloud objects, etc.) ● Other scale aspects are considered (time for light to reach planet, etc.)
3	Explanation uses a model and includes each of the following key aspects of the solar system: ● All 8 planets and the sun are represented and labeled. ● Calculations are correct. ● The distances or the sizes of the planets are modeled to scale ● An explanation of why it is difficult to show the relative distances to scale at the same time as showing the object sizes to scale is given. ● Strengths and limitations of model are evaluated.
2	Explanation uses a model and includes 3 of the 5 key aspects.
1	Explanation is based on common misconceptions

Analyze and interpret data to determine scale properties of objects in the solar system.

Key: Blue - SEPs Green - CCCs Orange – DCIs

Appendix F – Lesson Calendar

MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
APRIL 16 Teacher In-service NO SCHOOL	**17** Intro Lesson Phenomenon Introduction	**18** Lesson 1 What is the role of gravity in the motions of objects like planets, moons, asteroids and comets within our solar system?	**19** Lesson 2 How do different objects like planets, moons, asteroids and comets actually move within our solar system?	**20** Lesson 2 Continued
23 Lesson 3 What patterns of the apparent movement of objects across the sky can be observed from Earth?	**24** Lesson 3 Continued	**25** Lesson 4 How do the movements of these objects look different from space than they do from Earth?	**26** Lesson 4 Continued	**27** WyTOPP Test Prep NO CLASS
30 WyTOPP Test Prep NO CLASS	**MAY 1** Lesson 5 What is it about the E-M-S system that causes us to see objects like the moon & stars travel across our sky in predictable patterns?	**2** WyTOPP Testing NO CLASS	**3** Lesson 5 Continued	**4** Lesson 6 What initial observations can we make about the moon to help understand why we see it the way we do from Earth?
7 Lesson 6&7 What is it about the Earth-Moon System that causes us to see the moon rise and set at different times throughout the year?	**8** Lesson 8 What is it about the Earth-Moon-Sun System that causes us to see different parts of the moon at different times of the month?	**9** Lesson 8 Continued	**10** Lesson 8 Continued	**11** Lesson 8 Continued
14 Lesson 8 Continued	**15** FORMATIVE ASSESSMENT Phases of the Moon	**16** FORMATIVE ASSESSMENT Phases of the Moon	**17** Lesson 9 What is it about the Earth-Moon-Sun System that causes us to have solar eclipses?	**18** Lesson 9 Continued
21 Lesson 9&10 What is it about the Earth-Moon-Sun System that causes us to have lunar eclipses?	**22** Lesson 10 Continued	**23** FORMATIVE ASSESSMENT Planning for the Next Big Eclipse	**24** Alternate Schedule NO CLASS	**25** Lesson 11 Is the distance of the earth to the sun a factor that causes us to have seasons?
28 Memorial Day NO SCHOOL	**29** Lesson 11&12 If the seasons are not caused by the distance of the earth to the sun, what is it about the E-S system that causes us to have seasons?	**30** Lagoon Trip NO CLASS	**31** Lesson 13&14 How can we create a scale model to compare the distances between the objects in the Earth-Moon system? & in our solar system?	**JUNE 1** Lesson 14 How can we create a scale model to compare the distances between objects in our solar system?
4 Lesson 15 How can we create a scale model to compare the distances between, size of, and physical characteristic of objects in our Solar System?	**5** SUMMATIVE ASSESSMENT Scale Properties of Objects in the Solar System	**6** Alternate Schedule NO CLASS (Last Day of School)	**7**	**8**