Teachers’ Understanding and Usage of Scientific Data Visualizations
for Teaching Topics in Earth and Space Science

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ABSTRACT

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Scientific data visualizations are the products, and increasingly a core practice, of modern computational science across all domains. With recent science education standards emphasizing student engagement in practices, these scientific visualizations will only increase in their availability and use for K-12 science instruction. But teacher practice is key to the successful learning outcomes for these, and any, educational technology. This study follows eleven science teachers from initial exposure in a PD program through classroom use of scientific data visualizations that address topics in Earth and Space science. The framework of technological pedagogical content knowledge (TPCK) is used to examine key dimensions of teacher knowledge that are activated as they seek to understand the data visualizations and the conceptual models that they represent, select and integrate them into their curriculum, and ultimately use them for instruction. Baseline measures of select dimensions of TPCK are measured for all teachers. Two representative case studies allow for a deep analysis of TPCK in action throughout their professional and instructional experience, and finally the impact on teachers’ knowledge from the experience is examined, with implications for educative curricular material and PD program design.

Keywords: science education, data visualization, instruction
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Chapter 1

Introduction

A young teacher, new to teaching Earth Science, was having difficulties explaining hot springs and active volcanoes to her New York City middle school students. Every puddle of water they had ever seen had been cold and inactive. The teacher turned to a short documentary video called Yellowstone: Monitoring the Fire Below that she had seen in her Museum Resources course the week before. She showed the 7-minute video to her students and reported in her coursework that her students had asked her to show it to them repeatedly. In the video, they watched bubbling hot springs and geysers, partnered with a scientific data visualization of the physical processes underneath the surface of the earth that creates these hot spots. The teacher felt that this video made the concept real for her students. As a result, some of her students have chosen the topic of hot springs for their science research project. She expressed relief in having such a tool of demonstration and explanation and expressed a desire to continue using visualizations and videos in her science teaching.

Statement of Purpose

The Framework for K-12 Science Education (National Research Council, NRC, 2012) puts forth, “A vision for education in the sciences and engineering in which students… actively engage in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in these fields” (p. 8). Increasingly, access to natural phenomena and engagement in science practices includes using and interacting with digital data products like data visualizations or interactive computer models. And as digital technologies generate increasing amounts of data, and computational power expands exponentially, the impact of these tools and methods of science become increasingly critical to consider in the design of authentic, engaging educational experiences and instructional practices. Where once the only people to see an image from a satellite might be the astronomers or meteorologists working on the research team, now anyone with Internet access can browse and download terabytes of images, data sets and media from online websites and databases. Often, the websites that host these databases also include data viewers or tools that have been designed specifically for in-depth exploration and...
analysis of this data. But availability doesn’t mean accessibility or usability—especially for K–12 teachers and students.

I have had firsthand experience in the impact that digital data and media has had on learning and instruction. While I was a high school science teacher in the late 1990s, I experienced the quick transformation of media into digital formats, moving from showing my students artistic animations of the Earth-Sun-Moon system from a VRC tape to showing them digital videos of the actual Earth taken from an orbiting camera over the course of only five-years in the classroom. It was when I moved into an educational role at an informal science institution, the American Museum of Natural History (AMNH) in New York City, that the impact of this “data deluge” on science education became apparent to me. AMNH’s unique combination of scientific research, data visualization technology, and media production capacity, partnered with an educational mission, put it at the cutting-edge of exposing and immersing visitors/learners to previously distant, complex, and often inaccessible natural phenomena. This was particularly dramatic in the Hayden Planetarium, where new projection technology changed the nature of storytelling “under the dome.” The traditional star projector with dots of light representing stars that enabled stories of constellations and Earth-based celestial events was replaced with a digital dome projection system capable of 3D volumetric data visualizations that could immerse audiences in previously inaccessible systems and settings—from flying through a nebula to observing stars being born of gravitational collapse, to diving under the ocean to observe strange new forms of life around deep-sea hydrothermal vents.

It was during the development of educational materials and teacher professional development programs at AMNH that I first considered the affordances that data visualizations held for teaching and learning. As the opening vignette captures, I heard from teachers firsthand
the excitement and interest they had in bringing these data visualizations and digital tools back to their classroom, and the impact that it had on their students when they did. It was their interest and excitement that inspired me to undertake this research. This study emerged from the questions that I had of how to improve the design and usability of educational materials that leverage data visualizations, and how to support science teachers in using these types of digital resources to support learning. It is my hope that my experience as both a classroom teacher who used digital media and data and as a designer of curricular resources and professional development experiences that include data visualizations will provide insights that contribute meaningfully to the research base on teacher knowledge of, and instruction with, data visualization. My intent with this research is to inform the development of curricular materials and teacher professional development experiences that provide new tools and pathways to authentic, and accessible, student engagement in scientific practices.

This study uses a mixed methods to examine how science teachers understand, and instruct with, data visualization products to teach topics in Earth and Space Science. Eleven science teachers were observed from their initial engagement in the professional development experience through their curricular integration and classroom implementation of a designed set of data visualization-based resources. An analysis of videos of individual teacher interviews and the PD experiences, along with pre- and post-PD written surveys, has been used to examine how teachers understand data visualizations. Classroom observations and post-instruction teacher interviews were used to examine classroom implementation of data visualizations for instruction.
Organization of the Thesis

There are five chapters in this thesis. Chapter 1 includes the statement of purpose and this description of the overall thesis organization. Chapter 2 contains a review of relevant literature, the theoretical framework, and the research questions. The Methods, Results, and Discussion chapters are grouped together around each research question in a parallel arrangement, with the sequence corresponding to the sequential numbers of the research questions. Chapter 3 is a description of the methods used for each research question of this study. Chapter 4 is a presentation of the results, again presented by order of the research question. Chapter 5, the Discussion and Conclusions, first considers the results in greater detail and presents my interpretation of trends and practical consequences of the results that emerged from the data as well as connections to literature in the field of instructional design and teacher professional development. Chapter 5 then includes a brief conclusion that summarizes some of the main findings and presents some of the potential implications of this research.
Chapter 2

Literature Review

A New Vision for K-12 Science Education

In 2012, the National Academy of Science released *A Framework for K-12 Science Education* that offers a vision for science education where, “Students, over multiple years of school, actively engage in science and engineering practices and apply crosscutting concepts to deepen their understanding of each field’s disciplinary core ideas (NRC 2012, p. 2).” This guiding principle results in a framework that is comprised of the following three dimensions, that “must be woven together in standards, curricula, instruction, and assessments. (NRC, p 29)”:

1. Dimension 1 describes scientific and engineering practices.
2. Dimension 2 describes crosscutting concepts—that is, those having applicability across science disciplines.
3. Dimension 3 describes core ideas in the science disciplines and of the relationships among science, engineering, and technology.

“None of the dimensions can be used in isolation; they work together so that students can build deeper understanding as they grapple with making sense of phenomena or finding solutions to problems. As a result, learners can figure out more complex phenomena or design solutions to more perplexing problems. (Krajcik, 2015)” The subsequent release of the *Next Generation Science Standards (NGSS)* (NRC, 2013) embodies this multi-dimensional approach to learning in standards, or performance expectations, that incorporate all of these dimensions (Figure 2.1).

**Practices and Phenomena.** The *Framework* and the *Next Generation Science Standards (NGSS)* elevates science practices and situates them as a co-equal partners to what were traditionally content standards. This builds on a long tradition of inquiry learning, but because inquiry in the classroom, “historically came to be seen as solely pedagogical, (Pruitt, 2014)” and as a term, “has been interpreted over time in many different ways throughout the science
education community, part of [the NRC’s] intent in articulating the practices in Dimension 1 is to better specify what is meant by inquiry in science and the range of cognitive, social, and physical practices that it requires. (NRC, 2012)"

Figure 2.1. A Model of Three-Dimensional Science Learning

There are eight science practices explicitly defined in the Framework (the engineering practices are not considered in the scope of this thesis): a) asking questions, b) developing and using models, c) planning and carrying out investigations, d) analyzing and interpreting data, e) using mathematics and computational thinking, f) constructing explanations, g) engaging in argument from evidence, and h) obtaining, evaluating, and communicating information. These

![Figure 2.1. A Model of the Three Dimensions of Science Learning. Adapted from, “A Visual Representation of Three Dimensional Learning” by Houseal, A., 2016, Electronic Journal of Science Education, 20(9), p. 3.](image-url)
practices are connected to authentic science contexts in multiple “spheres of activity”;
Investigating, Evaluating, and Developing Explanations and Solutions. In all three spheres of
activity, scientists and engineers try to use the best available tools to support the task at hand,
which today means that modern computational technology is integral to virtually all aspects of
their work (NRC, 2012, p. 45).

To maintain a current and vibrant enactment of this vision for science education, one that
is connected to authentic science activities and will enable students to, “Have the skills to enter
careers of their choice” (NRC, 2012, p 1), it is critical to consider the advancement of modern
scientific tools and practices, specifically from computational and digital technologies, in the
design of learning experiences. An initial look at the impact that computational technology is
positioned to have on this vision for learning comes from examining how the Framework
envisions learning through K-12 as students build progressively more sophisticated explanations
of natural phenomena (NRC, 2012, p. 33-34). This progression of learning for the various
science disciplines includes specific reference to both the types of phenomena (microscopic,
macroscopic, etc.) that students are expected to encounter, as well as the kinds of learning
experiences (direct experience, use of representations, etc.) students are expected to have across
the grade levels. In the modern practice of science, digital tools and computational technologies
play an increasingly central role in both how natural phenomena are observed and understood, as
well as mediating many of the learning experiences that are envisioned. A few examples include
digital imaging devices and sensors that capture data and output imagery, thus enabling early
learners to make observations of phenomena that are not accessible due to distance or scale.
Moreover, increasingly dynamic and complex computer simulations and models of planetary
systems or atomic interactions that provide access to physical and astronomical phenomena in
the upper grade levels are becoming more widely available. By situating student access to, and engagement with, phenomena as core to the vision for learning science, it becomes critical that these digital tools and products of scientific research be designed for student learning and instructional use in many, if not most, domains of science addressed in the NGSS. In the next sections, a brief overview is presented of how the tools and methods of science are changing in this increasingly digital and computational landscape, and then consider how they are making their way into the science classroom.

**Digital Data and Data Visualization: A New Paradigm for Science**

“The Purpose of [scientific] computing is insight, not numbers.”

– Richard Hamming

The landmark report, *Science for All Americans* (Rutherford & Ahlgren, 1990), opens with a chapter on the Nature of Science. In the discussion of scientific inquiry, they identify the fundamental characteristic that all scientific disciplines share, “Their reliance on evidence” (Rutherford & Ahlgren, 1990). Advances in hardware and software for computation generate ever-increasing amounts of data and information, and by the 1980s some fields of science were facing, *Firehoses of information* as reported by McCormick et.al. (1987). By early 2000, science was struggling to deal with the data, and in 2011 *Science Magazine* issued a special “Data Edition” that addressed two critical themes that scientific research was facing: “Most scientific disciplines are finding the data deluge to be extremely challenging, and tremendous opportunities can be realized if [scientists] can better organize and access the data. (Science staff, 2011)” An example of this for just one of the eight scientific practices found in the NGSS (modeling) shows that, advances in hardware and software for computation provide an essential basis for improving modeling and simulation (NRC, Games for modeling and sim, 2010). Moreover, supercomputing
performance has increased by 14 orders of magnitude in the past 60 years. The most dramatic increase has occurred over the past 20 years, with the advent of massively parallel computers and associated programming paradigms and algorithms.

Managing and making meaning from all of this data drove the need to develop new scientific methods that could solve the problem of information-without-interpretation (NSF, 1987). In 1987, the National Science Foundation (NSF) first convened the Panel on Graphics, Image Processing, and Workstations to define and explore the emerging technology and computational field of data visualization, which was having a growing impact on the scientific community. Data visualization was a solution that was seen as an alternative to numbers, thus giving scientists the ability to more effectively visualize complex computations and simulations and to insure the integrity of analyses, and to provoke insights as well as communicate those insights with others (McCormick et al., 1987).

Over the decades since, data visualization has expanded to become an essential to the practice of science and engineering, as it provides a powerful means both to make sense of data and to then communicate what we’ve discovered to others (Few, 2007). As computational simulation emerged as the third paradigm in scientific research, joining theory and experimentation (Kennedy & Timson, 1994), data visualization became a critical tool in enabling the results and outputs of simulations to be used for communication and educational purposes. Even though scientific visualization had been used for research for over a century (Friendly, 2006), the NSF panel’s widely cited report, “Visualizations in Scientific Computing,” (McCormick et al., 1987) is considered the beginning of modern computer-supported data visualization as a field. For the research reported here, I will adopt their definition of the role of visualization as, helping people explore or explain data through software systems that provide a
static or interactive visual representation (McCormick et al., 1987). Visualization offers a more effective tool for examining a large amount of information that can’t be processed easily as numbers and complex graphs. It does this by utilizing high bandwidth channel of human visual perception to allow people to comprehend information orders of magnitude more quickly than they could through reading raw numbers or text (McCormick et al., 1987). This places visualization in the cognitive realm as a way of knowing in science (Kitchin, 2014), positioning it not just as a scientific practice, but often also as a part of the very construction and understanding of many of the disciplinary core ideas found in the NGSS.

Modern scientific visualization encompasses many diverse enterprises, including, a new type of graphic representation. This includes the creation of dramatic scientific images and their animation, an emerging academic field that combines elements of science, computing, semiotics, and the visual arts; and consequently the coordination of a suite of advanced technologies to collect, store, process, and image large data sets (Gordin & Pea, 1995). Each area of science has its own data sources and a unique visualization story to tell, but the fields of Earth and Space science have been at the forefront of these advancements. This is apparent in the original definition of the problem that the emerging domain of visualization was seeking to address (McCormick et al., 1987, p. 4), which included a list of the high-volume data sources at that time. All but one of them (medical imaging) were in the Earth and Space Sciences, and included modern technological advances such as supercomputers, orbiting satellites returning earth resource data, spacecraft sending planetary and interplanetary data, instrumental arrays recording geophysical entities, such as ocean temperatures, and seismic reflections from geological strata. Within decades after this initial NSF report was written, the volume and complexity of data continues to rapidly expand, and it is not unusual to hear words like,
“avalanche,” “catastrophe,” and “tsunami” being used as descriptors for the amount of data being gathered across the sciences. In the Earth sciences, increases in climate data were driven by many factors that included smaller and cheaper sensors that increased instrumental data sets globally, historical data sets and human records that were being made widely available as digital records, an increase in instruments onboard satellites that provide imagery and remote sensing data, and numerical and forecast climate models and simulations (Overpeck, Meehl, Bony, & Easterling, 2011). A similar exponential growth of data can be found in the Astronomical sciences, where advances in telescopes, detectors, and computational power (for simulations) are leading to expansions in the domains of this ancient field, “including the time domain, non-electromagnetic phenomena, magnetized plasmas, and numerous sky surveys in multiple wavebands with broad spatial coverage and unprecedented depths” (Borne, 2009, p. 1). All together, since 2003 digital information, including scientific data, accounts for 90% of all the information ever produced (Munzner, 2006).

With all of this information, visualization has become viewed as critical to our ability to process complex data (Fox & Hendler, 2011). However, more recently, data visualization itself is incurring a major expansion of its very domain. Visualization was traditionally seen as an end product of scientific analysis, a noun that could be in the form of an image (map, graph, etc.), video (dynamic data visualization), or some other media format. However, with increasing affordances of new database technologies, coupled with emerging Web-based technologies, there are new opportunities for making visualization part of the data exploration, enabling the scientist or researcher to become actively embedded in the analysis process. In this way, data visualization, as a verb, has the potential to impact multiple scientific practices that are found in
the Framework and NGSS; particularly analyzing and interpretation of data, carrying out investigations, and using models (NRC, 2012).

Models and Data Visualization. The visualizations used in this study can all be considered, in practice, to serve as models of an event or phenomenon that occurs on the Earth or in space. Models and modeling are now considered so fundamental in science that the, “understanding of, and ability to use, models is seen by many authors as central to an understanding of science (Gilbert & Boulter, 1998; Harrison & Treagust, 2000; Ramadas, 2009).” In the science education literature, there are three principal purposes for the use of modeling in the sciences: “(1) to produce simpler forms of objects or concepts; (2) to provide stimulation for learning or concept generation, and thereby support the visualization of some phenomenon; and (3) to provide explanations for scientific phenomena” (Coll & Lajium, 2011).

A feature of models is that they are, “human constructions [and] as such, they represent an approximation of reality” (Portides, 2007). In regards to Earth and Space science specifically, where phenomena are increasingly, and sometime only, observed or visualized via a computer simulation, it becomes critically important that models are purposefully designed for the learner/user, since research shows that, “a student or novice may confuse a highly successful, well established, model with reality, or the target it is being used to model” (Coll & Lajium, 2011).

Data Visualization in the Science Classroom

As the availability of scientific data and analysis tools expands beyond the realm of scientific research, so does the opportunity for educational innovation. The potential was seen early in the emergence of modern data visualization to make science education more accessible and to provide a means for authentic scientific inquiry (Gordin & Pea, 1995). And as
visualization has taken an increasingly central role in scientific research, Gilbert (2008) has argued that it should play a correspondingly important role in science education. As modern computational science and data visualization tools and methods become integral to many of the scientific practices in most of the areas of science in the NGSS, it is important to understand what this change means for teachers and teaching practice—who are critical to the success of the vision and its impact on student learning in science (Bybee, 2014).

The lack of agreement on terms used for data visualization makes a comprehensive review of the literature on the impact of data visualizations on science education difficult. Vavra et al. (2011) list several terms in education literature related to visualization including: a) visual representation, b) visual media, c) media literacy, d) visual communication skills, e) visual literacy, f) illustrations and g) media illustrations. Their literature review identified three distinct conceptualizations of visualizations that are useful for this study; namely, a) physical objects (geometrical illustrations, animations, computer-generated displays, picture-like representations), b) mental objects pictured by the mind (mental scheme, mental imagery, mental construction, mental representation), and c) cognitive processes that involve the interpretation of physical or mental visualizations (cognitive functions in visual perception, manipulation, and transformation of visual representations by the mind; concrete to abstract modes of thinking; picturing facts).

These distinctions are important for understanding the demands and contexts of visualization use and for determining the most effective application of visualization in the science classroom (Vavra et al., 2011).

To explore the impact that data visualization is, and will have, on science education, it is useful to situate it in the “Spheres of Activities for Scientists and Engineers” found in the Framework (NRC, p 45). Examining the first Sphere, Investigation, data visualization can be
viewed as both a noun \((n., \text{a mental or physical model})\) and a verb \((v., \text{using visualizations tools and techniques to make meaning from data})\). The expansion of computational power and visual display technologies is greatly expanding both of these realms, but more so as a verb.

As a noun, scientific data visualization offers new and varied representations of “The Real World.” The history of representations in the domains of science communication and education spans centuries and has been well documented and studied. More recently, advancements in graphic design and media production has pushed visualization “products” (visual displays, videos, interactive simulations, etc.) towards increasing “realism,” becoming more dynamic and three-dimensional and less numerical. This has expanded the accessibility, and therefore use-cases, for these digital phenomena into the public eye. A concrete example of this is the evolution of planetariums, which are found in the domain of informal science education and communication, that have moved away from domed theaters previously only representing the night sky. They have become immersive digital visualization theaters that have the capacity to situate the audience/learners in volumetric data visualizations that take them to places across time and size scales; i.e., “The Real World,” that they are unable to access in their everyday experiences. This evolution of visualization as a “way of knowing” has deeper implications for epistemology in science that are beyond the scope of this thesis, but Kitchin (2014) and others provide good overviews of this line of research.

In the classroom, access to data visualizations \((n.)\) occur via digital media that most often are in the formats of imagery, videos, simulations and games. These can be included/embedded in adopted curricula, or increasingly as supplemental materials. For this reason, research on data visualization integration and usage in classroom contexts for science instruction is often found in the body of research on multimedia learning (Hegarty, 2005; Kozma & Russell, 2005; Lowe,
Another mediating factor for data visualization use in science education is that access to the digital formats that data visualizations are often found in, are highly dependent on the information technology infrastructure of the classroom/school. This is a landscape that is changing dramatically with plummeting costs of classroom computers and investments in Internet connectivity for schools. Access to the Internet in U.S. schools is nearly universal. In 2008, 98% of U.S. public school classrooms had Internet access, and the ratio of students to instructional computers was 3:1, compared with a ratio of 7:1 in 2000 (National Science Board, 2014). However, these new “technologies do not guarantee effective learning (NRC, 2000).” Research has concluded that [technology], though remarkably enhanced for educational purposes, has great potential to enhance student achievement and teacher learning, but only if it is used appropriately (National Research Council, 2000).

These technological advancements are also having an impact on the school science laboratory, and the contribution that these environments make on science learning experiences. In the 2006 report, America’s Lab Report: Investigations in High School Science (NRC, 2006) the traditional definition of a laboratory experience was expanded in light of the increasingly computational and digital nature of scientific research, defining it to be:

Laboratory experiences provide opportunities for students to interact directly with the material world (or with data drawn from the material world), using the tools, data collection techniques, models, and theories of science. (NRC, 2006, p. 3)

The NRC document went on to further expand on these student experiences to include such affordances as interactions with astronomical databases, genome databases, databases of climatic events over long time periods, and other large data sets derived directly from the material world.
Many of these mirror the specific data sources listed in the NSF’s 1987 foundational report on the domain of data visualization.

Successful learning with data visualizations is mediated, like other digital technologies, by both teachers’ understanding of the educational affordances of them, as well as their instructional practices. Not much research exists on the experience of understanding and using data visualizations from the perspective of teachers and their instructional practice. Limited research on instructional strategies with these kinds of digital formats include the following:

1. Data visualizations and Science Education
2. Science with Data Visualizations
3. The Role and Voice of the Teacher

While the Framework rests on a new and growing body of research on learning and teaching in science, it also acknowledges that the evidence base on which the framework is incomplete (NRC, 2006). Moving forward, three areas of research are outlined that are needed to deepen the success of the current framework and inform future revisions. These include: a) changes in scientific knowledge and priorities, b) changes in the understanding of science learning and teaching across the K-12 spectrum, and c) changes in the understanding of how a given set of standards is interpreted, taken up, and used by a variety of players to influence K-12 educational practice and policy (NAS, 2015), with the last area having three related elements:

(1) research on K-12 teachers’ knowledge of science and science practices and their teaching practices; (2) research on effective professional development for supporting teachers’ understanding and uses of the standards; and (3) research on the resulting curricula, curriculum materials and technology-based tools, instructional approaches, and assessments. (NRC, 2006, pp. 311-12)
Almost every aspect of teaching science will be impacted by the growth of data visualization in the practice of science. This study seeks to examine this impact through the experiences of science teachers as poignantly envisioned by the NGSS while recognizing the ambitious goals of the NGSS, if successful, must rest with teachers (https://www.nap.edu/read/21836/chapter/2).

**Science Teacher Professional Development**

An understanding of the design and implementation of quality professional development for in-service science teachers has implications for this research study, since the initial science visualization exposure and teacher interactions and supports occur in the context of a PD experience.

Loucks-Horsley, Hewson, Love, and Stikes (1998) outlined a common vision of effective professional development experience for teachers in science that identifies the following seven principles: (1) driven by a well-defined image of effective classroom learning and teaching; (2) provide opportunities to build knowledge and skills; (3) modeling of teaching strategies and time for in-depth investigations; (4) building a learning community; (5) support for teachers as leaders; (6) providing links to other parts of the educational system; and (7) providing opportunities for continuous assessment and improvement. These should be taken into consideration in the design of teachers’ professional development activities. Other elements considered pertinent to the teachers’ professional development program in this study, such as resources, facilities, and duration, are included within some of these seven principles. A workshop is one of the many strategies for professional learning that is in alignment with this vision. A workshop is a structured experience outside of the classroom that offers teachers an opportunity to focus intensely on a topic of interest and learn from others with more expertise, as well as from their peers (Loucks-Horsley et al., 1998). The workshop strategy for a PD
experience allows for a more, “one size fits all” approach that can focus on developing awareness and introducing teachers to a new approach or technology (in the case of this study, to science visualizations).

The National Center for Improving Science Education (Loucks-Horsley et al., 1990) offers a model of a PD experience that includes four stages that informed the structure and design of the professional experience in this study. These four stages, and the targeted roles of the professional developer in each stage that were adopted for this study, follow:

1. Invite: create interest, generate curiosity, elicit responses that uncover what the teacher/learners know or think about the topic(s).
2. Explore: provide or stimulate multiple opportunities to explore an idea or strategy, observe and listen to the teachers/learners as they interact.
3. Explain: encourage teachers/learners to explain concepts and definitions in their own words, formally provide definitions, explanations and new labels.
4. Apply: Encourage and coach teachers/learners to apply concepts and skills to their own situations.

**Theoretical Framework**

Technological Pedagogical Content Knowledge (TPCK), a framework for teacher knowledge, is the conceptual framework used in this study. TPACK is conceptualized as the body of knowledge that teachers draw upon in their practice (Doering, Scharber, Miller, & Veletsianos, 2009). The framework consists of three main components (Figure 2.2), or domains, but is also concerned with transactional relationships among these components (Mishra & Koehler, 2006).
TPACK is built on the foundational work of Shulman’s (1986) pedagogical content knowledge (PCK) framework, which differentiates knowledge of subject matter (content) and knowledge of instructional considerations and strategies (pedagogy) and describes how these may interact or combine to form a unique form called pedagogical content knowledge (Shulman, 1986). While Koehler and Mishra introduced the term TPCK in 2005 (Koehler & Mishra, 2005a), it was the publication of their seminal article published in 2006 that presents the complete model of TPCK that is used in this study (Mishra & Koehler, 2006). This framework proposes technological knowledge (TK) as an additional domain, joining content knowledge (CK) and pedagogical knowledge (PK). This resulted in three paired dimensions of interactions, pedagogical content knowledge (PCK), technological content knowledge (TCK) and, technological pedagogical knowledge (TPK). Finally, technological pedagogical content knowledge (TPCK) was presented as an extended conceptual framework for understanding the complex, situated knowledge necessary to teach with technology effectively (Mishra & Koehler,
Brief descriptions of the seven dimensions of TPACK, as outlined by Mishra and Koehler (2006) follow:

1. **Content knowledge (CK)** is knowledge of the subject matter to be taught. Teachers must know about the content they are going to teach and how the nature of knowledge is different for various content areas;

2. **Pedagogical knowledge (PK)** is knowledge of the nature of teaching and learning. It includes teaching methods, classroom management, instructional planning, assessment of student learning, and an understanding of how students construct knowledge and develop habits of mind and positive dispositions towards learning;

3. **Technology knowledge (TK)** is a dynamic and evolving knowledge base that includes knowledge of technology for information processing and applications of technology in both work and daily life;

4. **Pedagogical content knowledge (PCK)** is knowledge of the pedagogies, teaching practices, and planning processes that are applicable and appropriate to teaching a given subject matter. Pedagogical content knowledge refers to the content knowledge that deals with the teaching process (Shulman, 1986);

5. **Technological pedagogical knowledge (TPK)** is the knowledge of how technology influences teaching and learning, as well as the affordances and constraints of technology with regard to pedagogical designs and strategies;

6. **Technological content knowledge (TCK)** is the knowledge of the relationship between subject matter and technology, including how technology influences and is used in exploring a given content discipline. Technological content knowledge refers to the knowledge of how technology can create new representations for specific content. It
suggests that teachers understand that, by using a specific technology, they can change
the way learners practice and understand concepts in a specific content area; and

7. Technological pedagogical content knowledge (TPCK) is a complex interaction among
the three principle knowledge domains (content, pedagogy, technology). Technological
pedagogical content knowledge refers to the knowledge required by teachers for
integrating technology into their teaching in any content area.

The TPCK framework provides the granularity necessary to examine the interplay of the
various overlapping dimensions of teacher knowledge activated during a professional
development experience and classroom instruction, and forms part of the rationale and
theoretical framework that guides the research questions for this thesis.
Research Questions

This study explores the following questions:

1. What do teachers bring to a data visualization experience that takes place in a professional development setting? Specifically:
   a. What is their content knowledge in the domain-specific content areas of Earth and Space Sciences?
   b. What digital media and technologies do they report utilizing in their instruction?
   c. What is the baseline understanding and usage of data visualizations that teachers bring to this experience?

2. When supplied with a set of data visualizations and support materials, how do teachers integrate (implement?) them into their domain-specific instruction?

3. How were teachers impacted from the visualization experience? Specifically:
   a. What was their change in content knowledge?
   b. What was their change in understanding of visualizations?
   c. What questions did teachers have about visualizations?
   d. What resources and supports did they reporting needing or wanting?
   e. What recommendations did they have for the PD program?
Chapter 3

Methods

An overview of the rationale for the methods is presented followed by information on the research setting, general methods of analyzing data, and issues of validity and reliability. This is followed with more detailed information on the methods used for each of the six research questions. An outline of the timeline for the research (Table 3.2) and a summary of the methods used for each research question (Table 3.3) are included at the end.

Overview

This exploratory study examined the impact of exposure to data-driven scientific visualizations on teacher knowledge and instructional practice. The research protocol was designed to collect data across multiple dimensions of teacher knowledge and practice during the course of a professional learning experience. The large quantity of qualitative and quantitative data collected were compiled into individual case studies and then explored through a comprehensive analysis of each dimension of teacher knowledge. Methods include qualitative open coding to identify emergent themes relevant to the research questions.

Disclosures and Researcher Background

As a researcher, I have been involved in multiple contexts and roles that have impacted my work on this study. First, I worked at the American Museum of Natural History (AMNH) for over seven years as an education manager. In that role I designed and delivered educational materials and professional development experiences for teachers that utilized data visualizations, including the ones used in this study. It was while I was at AMNH that I was able to obtain the data visualizations and media that were used in this study. Prior to working at AMNH I had been
a high school teacher in New York City, where I taught Physics and Astronomy at a private school in the Bronx.

At the time of this study, I was serving as both the Director of the informal science institution that hosted the professional development program, as well as a faculty member in Science Education at the host university.

**Research Setting**

This study was conducted at a public university in the Midwest. The context was a teacher professional development (PD) offering at an on-campus planetarium and informal science facility associated with the university’s College of Education. These PD offerings occurred in October 2009. The PD program was three hours in length and was offered on three separate dates to maximize participation. Participants only attending one PD program and were not paid for their involvement, although they did receive a DVD of data visualization videos and supporting resources, as well as a certificate of participation, upon the completions of the PD program.

**Participant Population**

This research study involved 11 in-service teachers (five females, six males) participating in one PD workshop aimed to enhance teachers’ content knowledge in Earth and Space Science and to support their use of data visualizations for science instruction. Teachers had an average of 15 years teaching experience (ranging from two to 36 years). It is important to note that two of the middle school teachers, with over 30 years of combined teaching experience (mainly in social studies and mathematics), were both in their first-year teaching science. Six of the 11 teachers taught high school, five taught middle grades, and one teacher taught grades 5 and 6 in a K-8 school (Table 3.1). Collectively, the eleven teachers held 27 teaching certifications among
the subject areas polled. While two teachers reported their certification in “Not Science,” the remaining nine teachers held a total of 25 certifications in science content areas, with Biology/Life Science having the highest frequency (N = 5), followed by Earth Science (N = 4). All teachers had certification in the grades(s) they were teaching at the time of the study. One high school teacher was certified and teaching Special Education. Five of the teachers reported that their school was in a suburban context, with four reporting an urban setting, and the remaining 2 reporting a rural location. Three teachers taught in schools that are classified as Title I schools (two urban and one rural). To be eligible for Title I status, at least 40% of a school's students must be from low-income families who qualify under the United States Census's definition of low-income, according to the U.S. Department of Education.

Table 3.1

*Participant Demographics and Code Names*

<table>
<thead>
<tr>
<th>#</th>
<th>Gender</th>
<th>Years Teaching</th>
<th>Grades teaching</th>
<th>School setting</th>
<th>Code Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>8</td>
<td>9-12</td>
<td>Suburban</td>
<td>Mary</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>36</td>
<td>12</td>
<td>Urban</td>
<td>Sam</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>22</td>
<td>10-12</td>
<td>Urban</td>
<td>Jon</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>2</td>
<td>6</td>
<td>Urban*</td>
<td>Bob</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>28</td>
<td>7</td>
<td>Suburban</td>
<td>Tom</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>10</td>
<td>9</td>
<td>Suburban</td>
<td>Amy</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>8.5</td>
<td>7</td>
<td>Rural</td>
<td>Cathy</td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>21</td>
<td>8</td>
<td>Rural*</td>
<td>Sue</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>10</td>
<td>10-11</td>
<td>Urban*</td>
<td>Dave</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>10</td>
<td>5-6</td>
<td>Suburban</td>
<td>Patty</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>9</td>
<td>10-12</td>
<td>Suburban</td>
<td>Mike</td>
</tr>
</tbody>
</table>
Teachers volunteered to engage in the PD program and research study. Teacher participants were recruited from regional school districts via recruitment fliers and emails that were distributed via the College of Education’s teacher and education alumni mailing lists, science coordinators for regional public school districts and the Archdiocese, and targeted professional teacher organizations related to science education (i.e., Physics Teacher Alliance).

Inclusion criteria for teacher participation included that teachers teach middle and/or high school grades, be able to deliver instruction in one or more topics that included weather, climate, or the solar system; and have the classroom technology infrastructure that allowed them to use videos in their instruction (i.e., projector and computer, access to a computer lab, or a DVD player). Recruitment and retention rates for the study were that over 20 teachers initially expressed interest in participating, with 15 teachers completing the application (pre-survey) and registering for a PD session, 12 teachers attending and completing a session, and 11 teachers completing the study (classroom implementation and completion of post-survey). For the purposes of reporting, all teachers were given code names (see Table 3.1).

**Research Design**

This research study examined a professional development experience designed to follow teachers through the entire experience of initial exposure to science data visualizations through teachers’ selection, curricular integration and classroom instruction with them. There were three milestones for participants involved in this study: a) the completion of the PD program workshop, b) the classroom implementation of data visualization(s) for instruction, and c) a closing interview and survey.

**Visualizations used in study.** At the core of this study’s methodology is a collection of five scientific visualizations from Earth and Space Science. All of the visualizations used in this
study share the characteristics of being data-driven—with digital information originating from satellite observations and computer simulations—as well as being dynamic temporally and/or spatially. Critical to the research protocol was the ability to have “less-produced” data-visualizations that had minimal annotation and on-screen information added to the underlying visual features of the model or data represented. Dubbed the “raw” versions for the purpose of this study, they each had corresponding “produced” visualization products that utilized the same data in the context of an annotated and narrated video that took the form of a more traditional instructional video.

The five visualizations in this study were selected due to their data originating from Earth and Space science research. They range in length from 0:45 seconds to 2:20, with an average length of 1 minute and 25 seconds. The specific topics were chosen due to researcher access to the production teams through her position at the American Museum of Natural History, who were able to provide the multiple versions of the visualization from different stages of their production. The five “produced” visualization products were drawn from Science Bulletins, specifically Earth and Astro categories, and from the Cosmic Collisions planetarium program, which features these data-driven visualizations as part of key storylines that are often found in the classroom and educational standards. The researcher worked with the AMNH production teams, who were able to isolate and render the data visualizations into excerpts clips that had no narration or text on-screen—which became the “raw” versions of the data visualizations.

Providing multiple representations—“raw” and “produced”—of the same phenomena in these corresponding visualizations gave teachers in the study more flexibility in both the level of content that they could bring into their instruction and the instructional strategies that they could implement with them, effectively expanding the instructional options and storylines available to
them. The design of this study depended on offering these different data visualization products to the teachers to support a wider range of pedagogical practices. An overview of the visuals and content of each of the five visualizations used in this study follows:

**Visualization 1: Global Cloud Patterns.** From a satellite's-eye view, Earth's atmosphere may seem like a chaotic swirl of clouds and currents. But patterns do emerge. Our planet's weather results from a complex interplay between the Sun's heat and Earth's air, water, and land. The rotation of the Earth helps guide where the air-moist, dry, cool, warm-tends to circulate. Over the long term—from as short as a few weeks to as long as a century—the "average" weather and how it changes is called climate.

The data used to produce the Global Cloud Pattern visualizations was collected every half-hour, day and night, from five weather satellites orbiting Earth. Their sensors measure not "clouds" per se, but infrared radiation (heat) in the atmosphere. White indicates cooler temperatures, and black indicates warmer ones. Therefore, the colder the cloud is, the whiter its trace will appear in the visualization. This also explains the "shadow" that sweeps east to west (right to left) across the data, called the diurnal cycle. As the Sun warms landmasses in the daytime, they darken on the data. Each sweep represents one day of the Earth orbiting the Sun. The data set used to produce these visualizations is, "globally-merged, full-resolution (~4 km) IR data formed from the ~11 micron IR channels aboard the GMS-5, GOES-8, Goes-10, Meteosat-7 and Meteosat-5 geostationary satellites,” and is available at the National Weather Service Climate Prediction Center site ([http://www.cpc.ncep.noaa.gov/products/global_precip/html/wpage.full_res.html](http://www.cpc.ncep.noaa.gov/products/global_precip/html/wpage.full_res.html)).

**Visualization 2: Earth’s Magnetic Shield.** The solar wind flows throughout the Solar System, except where planets or their magnetic fields get in the way. Not all planets act like big
magnets, but Earth does, protecting us from the solar wind’s supersonic particles. In this visualization, speeding particles appear as streaks heading away from the Sun. Between the Sun and Earth, a shallow bowl shape represents the “bow shock,” where the solar wind slows down. Around Earth, a billowing blue surface corresponds to the outermost reaches of the magnetosphere.

Figure 3.1. Global Clouds: Raw Version

Figure 3.1. Global Cloud Patterns Visualization: Raw Version. Used with permission by The American Museum of Natural History.

Figure 3.2. Global Clouds: Produced Version

Figure 3.2. Global Cloud Patterns: Produced Version. Used with permission by The American Museum of Natural History.
Scientists use computer models to simulate the behavior of Earth’s magnetic field interacting with the solar wind. In one such model, scientists studied the effects of a 2003 "solar storm" that caused radio blackouts and satellite malfunctions. During the storm, intense pressure from the solar wind pushed the bow shock and compressed Earth’s magnetic field. Computer
models help predict when the solar wind might become troublesome, knocking out satellites or endangering astronauts.

**Visualization 3: Sea Ice.** This visualization draws on data from the National Snow and Ice Data Center originating from two satellite instruments that measure emitted microwave radiation, which helps distinguish open ocean water from ice. The Scanning Multichannel Microwave Radiometer recorded data on sea ice conditions from October 1978 through August 1987. The Special Sensor Microwave Imager has provided data since June 1987.

This visualization of satellite data reveals seasonal patterns and long-term trends in the distribution of sea ice across the Arctic Ocean. Arctic sea ice reaches its lowest annual extent in September, after the warmth of summer. Sea ice in September 2007 hit a record low—50 percent smaller than it was in 1979, the first September that satellites measured sea ice. The significant downward trend of sea ice seen in recent years exceeds computer-model predictions of the effects of global warming.

Figure 3.5. Sea Ice Visualization: Raw Version

Figure 3.5. Sea Ice Visualization: Raw Version. Used with permission by The American Museum of Natural History.
Visualization 4: Our Moon. The peaceful glow of the moonlight in our sky belies a violent history that this visualization based on a computer simulation reveals. Evidence suggests that the Moon formed when a Mars-sized object collided with the young Earth, and computer models show us how such an impact could form our lunar companion in just one month.

Figure 3.6. Sea Ice Screenshot: Produced Version. Used with permission by The American Museum of Natural History.

Figure 3.7. Moon Formation Visualization: Raw Version. Used with permission by The American Museum of Natural History.
Figure 3.8. Moon Formation Visualization: Produced Version

![Figure 3.8. Our Moon Screenshot: Produced Version. Used with permission by The American Museum of Natural History.](image)

**Visualization 5: Global Ozone.** Ozone gas (O3) in the upper atmosphere shields Earth from the Sun's dangerous ultraviolet radiation. Since the early 1980s, scientists have been aware that manmade chlorofluorocarbons (CFCs) destroy atmospheric ozone worldwide. The greatest losses have occurred at the poles. Due to seasonal variations, the Antarctic ozone "hole" is most extreme in late September or early October. This visualization shows ozone measurements across the globe obtained by NASA's Total Ozone Mapping Spectrometer (TOMS) instrument and the Ozone Monitoring Instrument (OMI) aboard NASA's Aura satellite. Ozone levels are shown in measurements of Dobson units. The "hole" represents ozone levels lower than 220 Dobson units.
Figure 3.9. Global Ozone Visualization: Raw Version

Figure 3.10. Global Ozone Visualization: Produced Version

Figure 3.9. Global Ozone Visualization: Raw Version. Used with permission by The American Museum of Natural History.

Figure 3.10. Global Ozone Screenshot: Produced Version. Used with permission by The American Museum of Natural History.
**Professional development program.** The professional development (PD) program designed for this study was a three-hour workshop. It included a range of individual tasks and group discussion and planning to support an increase in teacher content knowledge. The topics addressed included: a) conceptual models and topics found in Earth and Space Science, b) various representations of the Earth and Space concepts in the form of dynamic, digital data visualizations, and c) support for the curricular integration and ultimate usage of these types of data visualizations for classroom instruction. The agenda and schedule for the professional development program is in Appendix A.

The planetarium setting, with its multitude of visual projection technologies, provided a robust technological infrastructure and a well-distributed physical layout that enabled different modes of data collection through flexible configurations—supporting both group discussions and individual interviews. For the individual interviews, the space allowed for up to six interview stations to be distributed in a manner that would not interfere audibly with each other.

**Educational resource package.** All visualizations used in the PD program were packaged and distributed to teachers in both the “raw” and “produced” versions. This goes beyond offering representations of a range of topics to also offering teachers multiple forms of the *same* visualization, with varying amounts of narration and annotation. This provides more flexibility for curricular integration and widens the instructional implementation options that are important to inform the research questions of this study. Teachers were given this package of visualizations towards the end of the PD program, before they began their instructional planning. It was delivered via a DVD that contained files of all the data visualizations that they encountered in the PD, both the raw and produced versions of the five visualizations. In addition, the DVD contained background information on the content and data found in the visualizations,
additional visualizations, and further resources that the teachers might find useful during their instructional planning and classroom implementation. The contents of this information package were informed by support requests from teachers during pilot versions of this study. Teachers in the study were also offered ongoing support and additional information, upon request. See Appendices H and I for the list of the visualizations and accompanying information packet provided to teachers during the PD program.

Table 3.2

*Phases of Study and Data Sources*

<table>
<thead>
<tr>
<th>Study Phase</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Baseline</td>
<td>• Pre-Survey</td>
</tr>
<tr>
<td></td>
<td>• Moon Formation Storyboard</td>
</tr>
<tr>
<td></td>
<td>• Weather &amp; Climate Concept Map</td>
</tr>
<tr>
<td>2 PD Program</td>
<td>• Visualization Exposure Interview</td>
</tr>
<tr>
<td></td>
<td>• Instructional Plan</td>
</tr>
<tr>
<td></td>
<td>• PD evaluation</td>
</tr>
<tr>
<td>3 Classroom Implementation</td>
<td>• Visualization Implementation Report</td>
</tr>
<tr>
<td></td>
<td>• Classroom Observations</td>
</tr>
<tr>
<td></td>
<td>• Individual Closing Interviews</td>
</tr>
<tr>
<td>4 Closing</td>
<td>• Post-Survey</td>
</tr>
</tbody>
</table>

*Phases of Study and Instruments*

This mixed methods study (Creswell & Plano Clark, 2018) had four key phases of data collection: recruitment and baseline data collection, PD program, classroom implementation, and closing collection (Table 3.2). A total of eleven instruments and protocols were adopted, adapted or developed to gather the data. The following sections describes data collection mechanisms
used for each phase of the study. This section is concluded with a data table that summarized the output of the varied data collection mechanisms in this study.

**Phase 1: Baseline Data Collection.** When a teacher expressed interest in participation in the study, and it was confirmed that they met the criteria for inclusion, they were sent an email that included a link to the pre-survey. All online surveys in this study, including the pre-survey, were administered online via the SurveyMonkey online survey service.

**Operationalizing TPCK.** The multi-dimensional Technological Pedagogical Content Knowledge (TPCK) framework (Mishra, 2009) provided a multifaceted, but integrated, view of teacher knowledge, acting like a prism through which to examine teachers’ experiences with data visualizations, both personally and in their instruction. The three overlapping domains of TPCK offer four additional dimensions that arise from the interactions between these three domains—for a total of seven dimensions.

*Figure 3.11. The TPCK Framework. Adapted from [http://tpack.org](http://tpack.org) © 2012 by tpack.org*
While the TPCK framework offers a total of seven distinct dimensions through which to explore teacher knowledge, only a subset of these dimensions pertinent to this study were operationalized and used to examine teacher knowledge. For example, the general domain of pedagogical knowledge, which includes general classroom management unrelated to content or technology, was not examined in this study. The constructs examined in this study, and their targeted dimensions, are outlined below:

1. **Content Knowledge:** the teachers’ knowledge about the subject matter to be learned or taught was isolated to the domain-specific content areas of Earth and Space Sciences. Within these domains, specific topics of focus in Space science were limited to the Earth-Sun-Moon system and within Earth science to Weather and Climate topics.

2. **Pedagogical Content Knowledge:** this is the pedagogical knowledge specific to teaching science and is critical to the examination of how data visualizations are integrated into curriculum, the instructional strategies used, and any teacher-reported student impacts that are examined in this study.

3. **Technological Knowledge:** this includes the reported personal and instructional usage of common digital and social media technologies by the subjects.

4. **Technological Content Knowledge:** this knowledge, “of the manner in which the subject matter (or the kinds of representations that can be constructed) can be changed by the application of particular technologies, (Mishra, 2009)” is critical to this study, since data visualizations provide teachers with additional representations of scientific phenomena.

5. **Technological Pedagogical Knowledge:** This knowledge of, “the pedagogical affordances and constraints of a range of technological tools, (Koehler & Mishra, 2009)” is important to consider when examining how the classroom usage of the data visualizations in this study are mediated by classroom technologies.

6. **Technological Pedagogical Content Knowledge:** This composite of all three domains, “is the bases of effective teaching with technology. (Koehler & Mishra, 2009)” and is not measured as another, unique dimension. In this study, an integrated view of a teachers’ working TPCK is described by aggregating the measures of the five previous dimensions and compiling them to construct a view of the depth of TPACK that each teacher has to draw on for their visualization experience and classroom instruction. This aggregate measure becomes core to examining teacher implementations in later research questions.

Baseline data on targeted dimensions of teacher TPCK was gathered through multiple methods in two different phases of the study. The pre-survey included specific sections designed
to address constructs of technology use (personally and for instruction), visualization understanding, content knowledge in domain-specific Earth and space science topics, and pedagogical content knowledge in Earth and Space Science, with key constructs aligned with dimensions of the TPCK framework. The same instrument was used as both the pre- and post-survey. The pre-survey (see Appendix B) was designed to provide data on subject demographics and to inform a picture of teachers’ baseline TPCK dimensions relevant for the scope of this study; specifically, a) technology usage, b) knowledge of visualization, c) content knowledge, and d) pedagogical content knowledge. Various instruments that had previously been developed and validated for teacher audiences were leveraged in the design of the items in these sections of the pre-survey instrument. A description of the specific instruments used for the domains of TPCK examined in this study follow:

**Technology usage.** A subset of questions from the Levels of Technology Implementation (LoTi) Survey (source https://www.loticonnection.com/survey-instrument) were used to measure technology usage on personal and instructional scales. Questions were selected due to targeted classroom technology related to the use and delivery of data visualizations. Used for staff development, assessment and school improvement, “The LoTi Framework has transformed into a conceptual model to measure classroom teachers’ implementation of the tenets of digital-age literacy as manifested in the National Educational Technology Standards for Teachers (NETS-T).” Through research over the past 20 years, it has achieved content, construct, and criterion validity (Moersch, 1995).

**Knowledge of visualization.** Since there were no pre-existing diagnostic tools surrounding visualization knowledge, the research drew from pilot testing experience and scientific visualization literature to ask teachers to define and give examples of key terms used in
the field of science visualizations, including “visualizations,” “simulations,” and “animations.” These were words teachers used interchangeably to describe science visualizations in pilot versions of this study, but which hold very different meanings in scientific and data information fields.

**Content knowledge.** Content knowledge in the domain-specific areas of Earth and Space science was measured through specifically selected, multiple-choice and open-ended questions drawn from a combination of validated instruments that included; the Astronomy Diagnostic Test v.2 (accessed at http://solar.physics.montana.edu/aae/adt/), the New York State Science Regents Examination in Earth Science (accessed at http://www.nysedregents.org/EarthScience/), and the Diagnostic Science Assessments for Middle School Teachers (DTAMS) (accessed at http://louisville.edu/education/centers/crimsted/diag-sci-assess-middle ). Items were selected for close alignment to the domain-specific content of the five data visualizations that were used in the study.

**Pedagogical Content Knowledge.** Baseline instructional practices for domain-specific content were measured with select questions from the DTAMS assessment related to Earth and Space Science domains (accessed at http://louisville.edu/education/centers/crimsted/diag-sci-assess-middle). These includes items developed and validated specifically to measure pedagogical practices in science education (Saderholm, Ronau, Brown, & Collins, 2010). The DTAMS assessment defines this knowledge as strategic for science teaching, knowing when, where, and how to best teach science. For this study, the use of pedagogical content knowledge was focused on the correction of student misconceptions about science by asking teachers to first recognize the students’ misconceptions, and then to describe the most effective ways that they would teach particular scientific concepts.
Phase 2: PD Program Data Collection. Multiple data collection instruments were used throughout the professional development workshops and are detailed in the following sections. Additionally, each instance of the three-hour long PD program was recorded, resulting in nine hours of video footage that was later transcribed and used as an additional source of data.

Moon Formation Storyboard. The teachers were asked to fill-in an empty storyboard (see Appendix D) with their visual and narrative understanding of the formation of the Earth’s Moon. This teacher task was completed in the beginning portion of the PD session, before teachers were exposed to data visualizations. The storyboard was a simple blank comic book-style page used to capture their ideas about the process and series of chronological events that led to the formation of Earth’s Moon, giving teachers the option to draw images or write narrative text, or both if desired. The resulting storyboards informed the initial mental models and content knowledge that teachers have regarding the domain-specific content of the Earth in the solar system.

Concept Map: Climate and Weather. Teachers constructed a concept map in the beginning portion of the PD session, before exposure to any data visualizations. Instructions for constructing the concept map were adapted from the methodology outlined in Novak (2008). A unique, two-phase, protocol was used that both enabled the participants to initially determine independently which concepts they wanted to include in their concept map, but then allowed the researcher to provide a list of eight key ideas and ask the participants to add these ideas to their concept map IF they were not already present. This second round of concept additions was done in a different color, allowing the researcher to easily determine which ideas the subject did not initially include.
The concept map data enabled the exploration of the initial mental models that teachers have regarding the domain-specific content of the Earth’s weather and climate. The teacher-constructed concept maps were assessed for content accuracy against the scientifically accurate strand map for Weather and Climate (http://www.project2061.org/publications/atlas/sample/a2ch4.pdf) in the AAAS Benchmarks Atlas for Scientific Literacy (Project 2061, 2007) to determine teacher content knowledge and inconsistencies with their mental models in the domain-specific content of weather and climate.

**Visualization exposure interview.** The Initial Interview is an individual interview between a teacher and a single interviewer that lasts about 30 minutes. The Individual Visualization Interview protocol (see Appendix C) was developed around exposure to, and interaction with, data visualizations. All five (5) data visualizations used in the Initial Interview were the “raw” versions that contained little, or no, labels or audio, allowing the teacher to apply their own narrative, and the researcher to probe the prior knowledge and mental model of the teacher in respect to the visual system viewed in the data visualization. The Initial Interview protocol also included questions to examine the level of teachers’ instructional usage of these types of visualizations and their understanding of the source of data used to develop the visualizations (the nature of the visualization).

Initial visualization interviews were done simultaneously for each teacher at dedicated interview stations during the PD program. Since each interview needed to be audio and video recorded, as well as present the visualizations to the teachers, the technological and A/V set-up for each station was important for fidelity among all interview data. Each interview station included; a laptop to view the visualizations in the *QuickTime* software program, the *Garage Band* software program to record an audio track of the interview, and one video camera
positioned over the shoulder of the subject to capture their interactions with the video on the screen and what they are viewing when they make specific comments or asked questions that were pertinent to the visual content on the screen at that time. Interview stations were distributed throughout the planetarium setting so sound from each interview would not interfere with the others.

**Instructional plans.** At the end of the PD session, teachers shared information about their initial instructional plans via a brief survey (see Appendix E). Teachers were also asked to consider which visualizations they wanted to implement, as well as identify possible barriers to implementation and predict benefits to their students. These questions were revisited within the closing interview, to “close the loop” and enable a comparison between teachers’ planned and enacted visualization implementations.

**PD evaluations.** A short PD evaluation survey (see Appendix F) was administered at the closing of the PD program to inform the design of professional development experiences and teacher resources that would increase the preparedness of teachers. It also allowed for a comparison of the level of preparedness that a teacher felt post-classroom implementation. The PD survey used for this study was modeled from a PD workshop survey that is often administered at the American Museum of Natural History and has been found to be useful for measuring teachers’ preparedness and needs upon the completion of a professional experience.

**Phase 3: Classroom Implementation Data Collection.** There were three opportunities for data collection in this phase of the study. They are described below, along with the instruments that were used.

**Classroom observations.** Classroom implementations were observed whenever the school setting and class schedules allowed for them. The researcher took field notes during the
class observations and later reviewed and coded them for key moments and quotes. Observations focused on the flow of classroom instruction, instructional strategies used by the teacher to deploy and engage students with the visualizations, technology usage, classroom setting, the nature of teacher student interactions, and overall quality of the visualization implementation.

**Visualization implementation report (optional).** For those teachers who were not able to schedule a classroom observation, an online Visualization Implementation Report survey (see Appendix G) asked teachers to report extemporaneous details and insights from a recent classroom implementation. This was also useful for teachers who used multiple visualizations and did not want to wait until the closing interview to capture multiple instances of visualization usage. The survey asked teachers about student responses to the visualization(s), additional resources and supports that they needed, and any recommended edits to the visualizations themselves that could have made them more useful in their instruction.

**Individual closing interview.** A semi-structured interview between the researcher and the teacher took place after the classroom implementation. It took place in either the teacher’s classroom (usually after an observation) or at the University Planetarium, the site of the PD program. The interviews ranged from 30-90 minutes in length and were driven by the teacher. Additionally, the total time was influenced by the amount of information and conversation that they wanted to have around the specific questions. The semi-formal interview protocol was designed to have teachers: a) describe and reflect on the enactment of the visualization(s) in their instruction, b) reassess the level of preparedness and supports that they obtained from the resources and PD session, and c) consider the impact on their students’ learning. In addition, teachers were presented with the content map that they had constructed during the PD session.
and asked to make any changes based on their experience with the visualizations and implementing them for instruction.

**Phase 4: Post-Survey.** Derived from the pre-survey (see Appendix B), the post-survey instrument consisted of the same items which included Technology, Visualization, and Content Knowledge sections from the pre-survey. This allowed for measurement of the impact from the PD program and classroom implementation on salient dimensions of teacher TPCK.

**Data Processing.** To enable analysis, all of the data collected was digitized and transcribed using the following methods.

*Audio and video processing.* Including individual interviews, and the three professional development sessions, a total of 18.5 hours of video footage was captured in this study. For all interview video data, separate audio and video tracks were recorded with optimal clarity of sound. The audio files were captured with *Garage Band* software and the video footage was captured into a MP4-file format. Video and audio tracks were then edited together, with the video tracks synched to their corresponding audio tracks, and combined into a single video for easy viewing and analysis of the individual interviews.

For PD session video data, the separate footage from both cameras (one focused on the teachers and the second on the presenter and screens) was edited together using *Final Cut Pro* into a single video file that allowed the researcher to analyze both viewpoints simultaneously in a split screen window. This allowed for correlation between what the teachers were seeing on the screen and what questions they were asking about it. These final interviews and PD workshop video files were then transcribed into documents.

*Storyboard and Concept Map Processing.* The Moon Formation Storyboards and the Concept Maps were both hand-drawn by the teachers. The completed storyboard forms were
scanned and saved as digital jpg files. The researcher used the CmapTools software program, developed by the Institute for Human and Machine Cognition’s (IMHC) and available for free at http://cmap.ihmc.us/, to transcribe the concept maps into a digital format that could then be exported into jpg image files.

**Hand-written surveys.** The Instructional Plan and PD Evaluation forms were both written by hand during the PD Session. The researcher later transcribed them into Word documents for analysis.

**Validity and Reliability.** Since individual interviews were implemented simultaneously during the PD session, up to five interviewers at a time were needed. Graduate students from the College of Education were recruited and trained to be interviewers. The Interview Protocol was written in the format of a script, with notes for the interviewer and the researcher trained the interviewers by sending them the protocol via email when they signed-up and asking them to come to the PD session 30 minutes early to get comfortable with their interview station, the technology, and run through the protocol. The researcher did not serve as an interviewer, so she would be able to float among the interviews to oversee the interviews and ensure fidelity among the interview methods and maintain the video and audio recording technology.

**Compiled Data.** All processed data was compiled, and a numerical system developed and applied that corresponded to items at the instrument level (see Table 3.3). This process normalized the data and allowed for ease in comparative analysis between different participants.

There are four phases of the study involving: a) Baseline, initial data gathering on demographics and initial content understandings, etc.; b) The PD Program (3-hour workshop); c) Classroom Implementation where the teachers included the PD experiences in their curriculum
planning and classroom practices; and d) Closing phase, where interview evidence and post-survey assessments were obtained.

Table 3.3

All Data Sources

<table>
<thead>
<tr>
<th>Phases of Study</th>
<th>Instrument/Data Source</th>
<th>Data #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>Pre-survey:</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>A. Demographics</td>
<td>1.1-1.13</td>
</tr>
<tr>
<td></td>
<td>B. Technology</td>
<td>1.14-1.19</td>
</tr>
<tr>
<td></td>
<td>C. Visualizations</td>
<td>1.20-1.25</td>
</tr>
<tr>
<td></td>
<td>D. Content Knowledge</td>
<td>1.26-1.36</td>
</tr>
<tr>
<td></td>
<td>E. Pedagogy</td>
<td>1.37-1.38</td>
</tr>
<tr>
<td>PD Program</td>
<td>Visualization Exposure Interview</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Transcript</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A. Viz 1: Clouds</td>
<td>2.1-2.7</td>
</tr>
<tr>
<td></td>
<td>B. Viz 2: Magnetic Field</td>
<td>2.8-2.14</td>
</tr>
<tr>
<td></td>
<td>C. Viz 3: Sea Ice</td>
<td>2.15-2.21</td>
</tr>
<tr>
<td></td>
<td>D. Viz 4: Moon</td>
<td>2.22-2.28</td>
</tr>
<tr>
<td></td>
<td>E. Viz 5: Ozone</td>
<td>2.29-2.35</td>
</tr>
<tr>
<td></td>
<td>PD session transcript</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Moon formation Storyboard</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Concept Map</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Instructional Plan</td>
<td>6.1-6.6</td>
</tr>
<tr>
<td></td>
<td>PD Session evaluation</td>
<td>7.1-7.5</td>
</tr>
<tr>
<td>Classroom</td>
<td>Classroom Observation Field Notes</td>
<td>8</td>
</tr>
<tr>
<td>Implementation</td>
<td>Viz Implementation Report (optional)</td>
<td>9.1-9.11</td>
</tr>
<tr>
<td>Closing</td>
<td>Closing Interview Transcript</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Post-Survey:</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>A. Technology</td>
<td>11.1-11.6</td>
</tr>
<tr>
<td></td>
<td>B. Visualizations</td>
<td>11.7-11.12</td>
</tr>
<tr>
<td></td>
<td>C. Content Knowledge</td>
<td>11.13-11.23</td>
</tr>
</tbody>
</table>

Methods for Investigating Individual Research Questions

In the following sections, the methods used to address each of the research questions are presented.
Research Question 1. What do science teachers bring to a data visualization experience that takes place in a professional development setting?

This research question addressed evidence needed to establish a baseline measure of teacher knowledge and practices that are relevant to their understanding and usage of data visualizations for science instruction. The TPCK framework for teacher knowledge was used, allowing for the examination of technology, content and pedagogical knowledge, aspects of which are all relevant to this study. Only the dimensions of TPCK that are relevant to experiencing, and teaching science with, scientific data visualizations were operationalized and examined. First, TPCK was unpacked into its three, overlapping domains and resulting seven dimensions. The following three sub-questions were then examined through the lens of their corresponding TPCK dimension(s):

A. What is their content knowledge in domain-specific content areas of Earth and Space Sciences (Content Knowledge)?
B. What do they understand about data visualizations? (Technological Content Knowledge)
C. What level of data visualizations use do they report in their instruction? (Technological Pedagogical Content Knowledge)?

Sub-question A. What is teachers’ content knowledge in domain-specific content areas of Earth and Space Sciences (CK)?

Multiple data sources were used to construct a view of teachers’ content knowledge in domain-specific content areas of Earth and Space Sciences. Data sources from the pre-survey that were used included demographics questions about courses taken in various science areas and 12 additional items of content knowledge questions that targeted concepts in Earth and Space Science. Additionally, there were two tasks for teachers at the beginning of the Professional
Development program that were designed to activate teachers’ prior knowledge about two concepts that were central to the content of the data visualizations. The artifacts that teachers generated in this task, concept maps and storyboards, provided another rich data source probing how robust and interconnected their mental models (ref, TBD) were about the Earth’s weather and climate and the scientific understanding of the process that formed the Earth’s Moon. All data sources used to inform a measure of teachers’ content knowledge are listed in Table 3.4.

Table 3.4

Data Sources for Content Knowledge Measure

<table>
<thead>
<tr>
<th>Study Phase</th>
<th>Data Collection Mechanisms</th>
<th>Data Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1: Baseline</td>
<td>Pre-Survey: Demographics</td>
<td>1.7-1.9</td>
</tr>
<tr>
<td></td>
<td>Pre-Survey: Content Knowledge</td>
<td>1.26-1.29, 1.31-1.35</td>
</tr>
<tr>
<td></td>
<td>Pre-Survey: Pedagogical Content Knowledge</td>
<td>1.37a, 1.38a</td>
</tr>
<tr>
<td>Phase 2: PD Program</td>
<td>Moon Formation Storyboard</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Concept Map</td>
<td>5</td>
</tr>
</tbody>
</table>

Pre-Survey: Demographics Section. Demographic data collected from the participants in the Pre-Survey regarding their educational background included the number of undergraduate and graduate courses, or in some cases credit hours, that teachers took in the Earth and Physical Sciences. Data regarding physical science coursework was considered in this analysis due to the fundamental physical nature of many of the topics addressed in the data visualizations in this study (e.g., the electromagnetic spectrum, charged particles in a magnetic field, thermodynamics, heat, gravitational forces, condensation and accretion, etc.). The total number of courses for
each teacher was then transposed into ranked categories of High, Medium, or Low to describe their level of background coursework in the Earth and the Physical Sciences. For example, a teacher who took five or more courses received a ranking of High, those with three or four courses received a ranking of Medium, and teachers with zero to two courses were ranked as having a Low level of background coursework. Finally, the separate scores for Earth and Physical sciences were aggregated into a single, overall level of background coursework by averaging together the Earth and Physical Science ranking. A teacher with the same level for both would receive the same overall level, but when levels differed, the following scoring was applied: A high and a low level would combine into an overall medium level, and two adjacent levels would be combined into the lower of the two (i.e., medium and low combines into a low score).

*Pre-Survey: Content Knowledge.* The Pre-Survey included a total of eleven items, both multiple choice and open-response, that focused on content in domain-specific topics of Earth and Space Science. Together, these eleven items provided the majority of the data that would inform the measure of the teachers’ content knowledge. The two question formats required separate scoring processes for analysis.

Six of the eleven questions were multiple-choice questions (1.26-1.28, 1.33-1.35). For each correct answer given, participants received one point, with no points received for an incorrect answer. In a few cases, multiple answers were selected, with one of them being the correct answer. In these instances, partial credit of 0.5 points was awarded. An overall score was obtained by adding together all individual item scores, with the maximum possible score of 6.

The remaining five of the eleven content questions in the pre-survey were open-ended response questions. Responses for each of these were scored against scientifically accurate
answers, with the teachers receiving one point for an answer that reflects the scientifically accurate understanding, and no points if the scientific understanding is not reflected. A scoring example for one of these types of questions follows.

The question, “What causes the weather? (Q 1.29)” probes the participants’ understanding of both the structure and interaction of the Earth systems, particularly within the atmosphere. While answers to this question often included common descriptors of the atmosphere (i.e., temperature, pressure, humidity, etc.), this question was intended to probe the participants’ mental model of the Earth as a dynamic, interconnected system. “Weather, fundamentally, is caused by the Sun’s incoming light, and this energy striking the spherical Earth tilted on its axis results in differential heating of the Earth’s land and water. Partnered with the constant rotation of the Earth, this sets-up temperature and humidity differentials within the atmosphere that drive the unending circulation of air masses that form the basis of our planet’s weather systems. (Lutgens, Tarbuck, & Tasa, 2007)” To receive the top score of one point for this open-response question, the participants had to include differential heating in their answer. A few coding examples for this question are in Table 3.5 (emphasis mine).

Table 3.5

**Scoring Example for Question 1.29**

<table>
<thead>
<tr>
<th>Open-Response</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>uneven heating and cooling of the earth’s surface. this is due to the different absorption and radiation characteristics of land and water</td>
<td>1</td>
</tr>
<tr>
<td>changes in atmosphere, change in seasons, wind, moisture, temperature</td>
<td>0</td>
</tr>
</tbody>
</table>
Compiled Pre-Survey Measures: Content Knowledge. The total scores from the multiple choice and open-ended responses were added together into a composite numerical score of teachers’ content knowledge as measured from pre-survey data. The maximum score possible was 11. This composite score was then transposed into three descriptive levels of content knowledge; High (eight to eleven points), Medium (four to seven), or Low (zero to three points) content knowledge.

Moon Formation Storyboard. In the Content Exploration portion of the PD Program, before teachers were exposed to the Data Visualizations, each teacher individually filled out a blank storyboard with their own text and/or drawings that represented their baseline understanding of the physical process that was responsible for the formation of the Earth’s Moon. The textual component of their storyboard responses provided another source of data to inform the participants’ baseline content knowledge, in this case regarding the history and structure of the Earth in the Solar System.

After extracting the text from the moon formation storyboard, the participants’ responses were analyzed against the following, scientifically accurate description of the formation of the moon excerpted from the narration script that was written to accompany the visualization in the Cosmic Collisions planetarium show (2006). Key content points about the formation of the moon were identified by the researcher (see underlining below) and were the focus of the scoring.

A PROTO-EARTH, cratered and molten, was a planet still forming In those early days, our solar system was swarming with large chunks of rock, some as big as planets. A number of them had orbits that brought them close to Earth. {Astronomers think the collision happened about 4.53 Billion years ago; about 30-50 million years after the Solar System began to form.} A partially-formed planet approximately the size of Mars heads towards the young Earth. This one got a little too close…And WHAM! The rock slams Earth. Molten debris sprays everywhere. The collision nearly destroyed the Earth, spraying molten rock out into space. Most of this rock fell back onto our shattered planet.
Transition to accretion epoch: Earth is now surrounded by a SWIRLING MASS OF MOLTEN DEBRIS, which flashes here and there, as pieces stick together. A glowing yellow-red band hugs Earth’s equator. The rest of the rock stayed in orbit. The force of gravity kept it from escaping out into space. As these jagged rocks revolved around Earth, gravity drew them towards one another. They began to collide, fusing together into larger chunks. Within weeks, these chunks combined with others, growing bigger and bigger. And in less than a month… incredible as it may seem…our moon was formed. That’s right. It took only one month to create our moon.

This particular answer was utilized for scoring subject responses due to its narrative format being aligned with the storyboard approach to data collection. This approach was taken because it was the narration from one of the data visualizations, Viz 2. Our Moon, in the study. By coding teachers’ storyboards against the narration for the data visualization that they would later encounter in their interview visualization, it provided a direct comparison between their initial mental model of this process, and later responses in their Individual Visualization Interviews. Subject responses were scored for a High, Medium, or Low level of scientific accuracy. Two scoring examples follow for storyboards that represent a High and Low level of accuracy.

In the first sample response, the following textual component of the storyboard (Figure 3.12) was extracted for analysis:

Earth is a cooling and condensing rock (billions of years ago)
Catastrophe! A meteor hits the Earth about 50 million years after formation
Dust, ash, rock bits fly everywhere
Part of the Earth breaks off and gravity consolidates the moon
Moon provides light and tidal waves that influence life on Earth
Moon slowly continues to move away from Earth. What would life be like without the Moon?

After being analyzed against the scientific narrative answer key, this storyboard is scored at a High level of Content Knowledge. In the second example (Figure 3.13), the following text was extracted from the storyboard and scored at a Low level of science accuracy:
In the beginning …swirling mass of stuff  
Gravity began to pull some stuff together  
By the time the moon was formed the Earth was already orbiting the Sun  
As the Earth’s gravity pulled the Moon down toward it  
It was circling the Sun  
So, the moon can never fall to the Earth…it can only orbit around it

Weather and Climate Concept Map. At the beginning of the Professional Development program, in addition to the Moon Formation Storyboard, teachers were also asked to construct a concept map around the focusing question, “What are the basic principles that contribute to maintaining and causing changes to weather and climate?” This task provided the context and opportunity for the teachers to consider their understanding about weather and climate topics. A two-step protocol adapted from (Novak, 2008) asked participants to initially determine which concepts they wanted to include in their concept map. But after their initial concept map had been sketched out, participants were asked to add eight concepts that are critical to the domain-specific topics of weather and climate to their concept map IF they had not initially included

Figure 3.12. Example Moon Formation Storyboard: High Score
them in their concept map. Different colors were used to denote which terms that had not been initially included were adding in this second round. The eight concepts that were required for inclusion were; temperature, winds, water cycle, atmosphere, climate change, seasons, weather, and climate. This two-phase protocol allowed the researcher to easily determine which ideas the subject has not initially included, but to also see how their knowledge about these specific concepts core to their understanding of weather and climate was constructed and connected.

Participants’ concept maps were scored against the scientifically accurate Weather and Climate strand map from the American Association for the Advancement of Science’s *Atlas for Scientific Literacy* (AAAS, 2006). The AAAS strand maps include the specific ideas and skills that serve as goals for student learning that are most relevant to understanding the main concepts for each strand, in this case Weather and Climate, providing a useful key to score participants’ concept maps (accessed at [http://www.project2061.org/publications/atlas/sample/a2ch4.pdf](http://www.project2061.org/publications/atlas/sample/a2ch4.pdf)).
Subject concept maps were scored as reflecting a High, Medium, or Low level of scientific knowledge regarding the topics of climate and weather. These scores were determined based on the following criteria: a) the initial inclusion of eight key concepts (temperature, winds, water cycle, atmosphere, climate change, seasons, weather, and climate), b) the number of accurate individual ideas included in the concept map, c) the level of interconnection between the concepts, which demonstrates a more integrated understanding of the Earth system, and d) the scientific accuracy of the interconnected phrases.

An example of the scoring process that was applied to each concept map follows for a concept map that received a High score (see Figure 3.14).

The first step in analysis of the content maps was to assess the content map for the number of concepts included, and to visibly assess the level of cross-linking between the concepts. For example, the concept map in Figure 3.14 shows a high level of cross-linking between concepts. This higher frequency of interconnections visibly demonstrates a richer, more integrated understanding of the complex, interacting factors of Earth’s weather and climate. For comparison, Figure 3.15 shows an example of a concept map with less cross-linking between concepts, and therefore demonstrating a lower depth of understanding of weather and climate as a dynamic, multidimensional system.
In the next step of analysis, the scientific concepts included in the map (see Figure 3.14) were listed and examined to determine how many of the eight key concepts were initially—and accurately—included in the concept map. This initial concept list includes the following instances:

1. Weather: short-term changes (snow, tornado, heat wave, wind, storm)
2. Climate: long-term changes (biomes)
3. Temperature
4. Precipitation
5. Amount and angle of sunlight (latitude)
6. Atmospheric gases
7. Global Climate change
8. Mountains, Coastlines, Vegetative Cover
Only one key concept was initially left out, “water cycle,” and during the second step of the mapping protocol it was accurately situated within the concept map, as represented in red (Figure 3.14). The initial inclusion of seven of the eight key concepts in her map reflects a higher degree of scientific content knowledge, which will be reflected in her final score.

In the next step of the analysis, all of the individual concepts and their linking words were extracted from the concept map and compiled into a single list of statements. This allowed them to collectively be reviewed for their level of scientific accuracy. To continue with our example analysis, this concept map included 25 individual concepts and descriptors, and 21 linking words, to develop a total of 38 propositions about the weather and climate in her concept
map. The individual statements in the concept map corresponding to the 38 propositions are listed below.

1. weather - is - short term changes
2. short term changes - causing - snow
3. short term changes - causing - tornado
4. short term changes - causing - heat wave
5. short term changes - causing - thunderstorm
6. short term changes - causing - wind
7. thunderstorm - contributes to - precipitation
8. precipitation - is part of - the water cycle
9. wind - causes changes in - temperature
10. temperature - influences - plant and animal life
11. weather - is monitored by - NOAA
12. weather - is interrelated to - climate
13. climate - is monitored by - NOAA
14. climate - is - long term changes
15. long term changes - determined by - latitude
16. long term changes - determined by - seasonal change
17. long term changes - determined by - atmospheric gases
18. long term changes - determined by - amount and angle of sunlight
19. long term changes - creating - biomes
20. biomes - such as - temperate
21. biomes - such as - polar
22. biomes - such as - tropical
23. polar - causing evolutionary adaptations in - plant and animal life
24. latitude - is related to - temperature
25. amount and angle of sunlight - produces - average temperature
26. amount and angle of sunlight - drives - seasonal change
27. amount and angle of sunlight - drives - plant and animal life
28. amount and angle of sunlight - drives - the water cycle
29. seasonal changes - linked back to - weather
30. atmospheric gases - leading to - global climate change
31. global climate change - causing more changes to - biomes
32. global climate change - causing more changes to - vegetative cover
33. global climate change - causing more changes to - coastlines
34. global climate change - causing more changes to - mountains
35. global climate change - causing more changes to - precipitation
36. vegetative cover - also influences - temperature
37. coastlines - also influences - temperature
38. mountains - also influences - temperature
When analyzed for content, the statements about weather and climate in this concept map are scientifically accuracy and reflect a high depth of content knowledge.

When all of these aspects of the concept map are taken together—the initial inclusion of seven of the eight key concepts, the accurate integration of the remaining concept, the high number of concepts and varied descriptors, the many cross-links that demonstrate integrated knowledge about climate and weather, and the scientific accuracy of the many statements that were developed within the concept map—this concept map (Figure 3.14) reflects a High level of content knowledge and a robust and interconnected mental model about the Earth’s weather and climate. This analysis process was repeated for each subject.

*Content Knowledge Overall Scores.* Scores from the pre-survey items, moon formation storyboard, and concept map instruments, along with level of background coursework in the Earth and Physical sciences, were compiled together into a table to provide an aggregate view of the measure of teacher’s baseline content knowledge from across each of these instruments.

A single, composite measure of the level of a teachers’ content knowledge was then developed by applying the following scoring rules. If a teacher had three or four scores at the same level, then they received an overall score at the same level. If a teacher had two scores each from two adjacent levels, for example two High and two Medium scores, then they received a blended score of Medium/High. These two rules were able to address all permutations of teachers’ scores, and enabled a single, composite score for teachers’ overall content knowledge to be developed.

*Teachers’ Understanding of Science Visualization (Sub-question 1 B).* The following composite questions were subsumed within Sub-question 1B.

*What do science teachers understand about data visualizations? Specifically:*
1. What are teachers’ conceptions of them?
2. What is the nature of their data and sources?

Two data sources were used to explore teachers’ understanding and conceptions of data visualizations; responses from the pre-survey and transcripts of the Individual Visualization Exposure Interviews. Analysis procedures for both of these data sources are in the following sections.

Teacher Conceptions of Visualizations. The initial understanding that teachers’ have about scientific visualizations prior to exposure were probed in the presurvey using an open-response item that asked, “What is a ‘scientific visualization’?” Open responses were coded against three distinct conceptualizations of visualization that were found to be important in the literature (Vavra, et.al., 2011). The definition of these distinctions, and the code that was assigned to them, are in Table 3.6.

Multiple codes could be applied to a single teacher response. In addition to coding for overall category, descriptors used by the teachers in their open responses were extracted and grouped for each coding category. This provided further granularity and insights into the specific ideas that teachers’ have about these conceptions of science visualizations.

Table 3.6

<table>
<thead>
<tr>
<th>Conceptualization of Visualization</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visualization <strong>objects</strong> can be pictures,</td>
<td></td>
</tr>
<tr>
<td>three-dimensional models, illustrations,</td>
<td></td>
</tr>
<tr>
<td>computer-generated displays, simulations,</td>
<td></td>
</tr>
<tr>
<td>animations, videos, etc. Objects can be</td>
<td></td>
</tr>
<tr>
<td>displayed in a variety of media formats.</td>
<td></td>
</tr>
<tr>
<td><strong>Introspective</strong> visualizations are mental</td>
<td></td>
</tr>
<tr>
<td>objects pictured by the mind. They can be</td>
<td></td>
</tr>
<tr>
<td>thought of as imagined visualization objects.</td>
<td></td>
</tr>
</tbody>
</table>

(continued)
Table 3.6

*Code Definitions for Visualization Conceptions (continued)*

<table>
<thead>
<tr>
<th>Conceptualization of Visualization</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Interpretive</strong> visualization involves making meaning from visualization objects or introspective visualizations in relation to one’s existing network of beliefs, experiences and understandings. An interpretive visualization involves a cognitive action—a change in thinking as a result of interaction with a visualization object or an introspective visualization (Phillips, Norris and Macnab 2010).</td>
<td>IP</td>
</tr>
</tbody>
</table>

*Nature and Source of Visualization Data.* The visualization exposure interview protocol included one item that provided data to inform how teachers understand the source, and therefore nature of, the data used to produce each of the five visualizations in this study. The interview question, “Where do you think the data to make [the] visualization comes from?” was asked during the Individual Interview upon initial exposure to each of the five visualizations, providing five unique responses for each of the 11 teachers. Teachers’ responses were compiled from interview transcripts, grouped by similar answers, and measured for frequency of each answer. A single response from a teacher could result in multiple descriptors. Results were then grouped by visualization into the two main topics in this study, Earth (viz., 1, 3, and 5) and Space (viz., 2 and 4), for general comparison.

*Teachers’ Use of Science Visualization for Instruction (Sub-question C). What level of data visualizations use do teachers report in their science instruction?*

Transcripts of the Visualization Individual Interviews provided the data to answer this question. During the interview, teachers were asked, “Have you ever used something like this before in your teaching? If so, what was it and where did you get it from (internet, DVD, etc.)?” This question was asked for each of the five data visualizations. Since teachers were asked this
question at the time of initial visualization exposure, with each visualization still on-screen in front of them, responses can be seen to reasonably reflect their instructional usage for the specific types of dynamic data visualizations used in this study.

**Question 2: Classroom Implementation.** *When supplied with a set of data visualizations, how do teachers integrate and implement them into their domain-specific instruction?*

The story of a teachers’ experience with data visualizations from initial exposure through classroom instruction is a dynamic, multi-dimensional view of TPCK in action. To answer this question, two representative teachers were identified from the pool of participants and case studies were developed and compared across various dimensions of TPCK. The following steps were followed in the selection of two representative teacher cases:

1. Due to the classroom observation and field notes being a rich data source for triangulating informing instructional strategies used, only the four teachers who had classroom observations were considered for case studies.
2. Subjects’ presurvey data was examined to identify two cases who taught similar grades and had comparative school contexts and classroom technology.
3. Subjects’ classroom observations were examined for use of the same type(s) of visualization, Earth or Space, in their instruction.

**Question 3: Teacher Impacts and Needs.** *How were teachers impacted from the visualization experience?*

This research question examined the impact that exposure to, and instruction with, scientific visualizations had on the teachers in this study. The “impact” on teachers was unpacked and operationalized into five sub-questions for Question 3 listed below.

A. *What was teachers’ change in content knowledge?*
B. *What was their change in understanding of visualizations?*
C. *What questions did teachers have about visualizations?*
D. *What resources and supports did they reporting needing or wanting?*
E. *What recommendations did they have for the PD program?*
Methods of analysis for each of these questions follow in dedicated sections.

**Change in teachers’ content knowledge (Sub-question A).** Data sources from the post-survey were used to examine how teachers’ content knowledge in Earth and Space topics changed over the course of the study. The post-survey included a sub-set of the items in the pre-survey that addressed content knowledge. There were six multiple choice and three open-response questions (11.13-11.22) included in the post-survey, corresponding to items 1.26-1.32 in the pre-survey. Responses from the post-survey were analyzed using the same methods as the pre-survey responses. Finally, scores from pre- and post-survey results were compiled into a single table, and changes between pre- and post-survey results were calculated.

**Change in teachers’ visualization understanding (Sub-question B).** Changes in teachers’ understandings about scientific visualizations were probed in the post-survey using the same open-response item that asked in the pre-survey, “What is a ‘scientific visualization’?” Open responses were again coded against three distinct conceptualizations of visualization that were found to be important in the literature (Vavra et al., 2011). The definition of these distinctions, and the code that was assigned to them, are in Table 5.11. Multiple codes could be applied to a single teacher response. In addition to coding for overall category, descriptors used by the teachers in their open responses were extracted and grouped for each coding category, offering specifics of the ideas that teachers’ have about visualizations.

**Method for sub-questions C, D and E.** The remaining three sub-questions used emergent coding to first identify themes that were robust and repeated across multiple participants and/or settings. Representative quotes were then selected that embodied the main thrust of the themes. The same data sources were used to address all three sub-questions and include; individual
visualization interview transcripts, PD session transcripts, instructional plans, PD session evaluations, and closing interview transcripts.
Chapter 4

Results

Research Question 1

What do science teachers bring to a data visualization experience that takes place in a professional development setting?

Content knowledge (Sub-question 1A). What is teachers’ content knowledge in domain-specific content areas of Earth and Space Sciences?

Data from the pre-survey and two teacher tasks during the PD program were used to construct a view of teachers’ content knowledge in domain-specific content areas of Earth and Space Sciences. Results of analysis for each of these three sources follows.

Pre-Survey: Demographics Section. Demographic data provided by the participants in the Pre-Survey regarding their level of background coursework in the Earth and Physical Sciences was transposed into ranked categories of High, Medium, or Low. Results are in Table 4.1.

Table 4.1

Level of Teacher’s Coursework in Earth and Physical Sciences

<table>
<thead>
<tr>
<th>#</th>
<th>Code Name</th>
<th>Earth</th>
<th>Physical</th>
<th>Composite Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mary</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>2</td>
<td>Sam</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>3</td>
<td>Jon</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>4</td>
<td>Bob</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>5</td>
<td>Tom</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>6</td>
<td>Amy</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>7</td>
<td>Cathy</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>8</td>
<td>Sue</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>9</td>
<td>Dave</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>10</td>
<td>Patty</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>11</td>
<td>Mike</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
**Pre-Survey: Content Knowledge.** The Pre-Survey included eleven items, in multiple choice and open-response formats, that together informed the measure of the participants’ baseline content knowledge upon entering the study. Results of analysis for each of these two types of question follow.

*Multiple-choice Questions.* An overall score for the six multiple choice items included in the pre-survey was obtained by adding together all individual item scores, with the maximum possible score being 6 (see Table 4.2).

Table 4.2

*Content Knowledge: Multiple-Choice Scores from Pre-Survey*

<table>
<thead>
<tr>
<th>#</th>
<th>Code Name</th>
<th>Total Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mary</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>Sam</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Jon</td>
<td>4.5</td>
</tr>
<tr>
<td>4</td>
<td>Bob</td>
<td>5</td>
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<tr>
<td>5</td>
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<td>4</td>
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<tr>
<td>6</td>
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<td>5</td>
</tr>
<tr>
<td>7</td>
<td>Cathy</td>
<td>5.5</td>
</tr>
<tr>
<td>8</td>
<td>Sue</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Dave</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>Patty</td>
<td>4</td>
</tr>
<tr>
<td>11</td>
<td>Mike</td>
<td>6</td>
</tr>
</tbody>
</table>

*Open Response Questions.* The remaining content knowledge data from the pre-survey resulted from five open-ended response items. The compiled scores for each teacher, with a possible maximum of 5, are listed in Table 4.3.
Table 4.3

**Content Knowledge: Open-Response Scores from Pre-Survey**

<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>Score 1.29</th>
<th>Score 1.31</th>
<th>Score 1.32</th>
<th>Score 1.37a</th>
<th>Score 1.38a</th>
<th>Total Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mary</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Sam</td>
<td>1</td>
<td>1</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
<td>4.5</td>
</tr>
<tr>
<td>3</td>
<td>Jon</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Bob</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Tom</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>Amy</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Cathy</td>
<td>0</td>
<td>1</td>
<td>0.5</td>
<td>1</td>
<td>0</td>
<td>2.5</td>
</tr>
<tr>
<td>8</td>
<td>Sue</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Dave</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>Patty</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>Mike</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

*Compiled Pre-Survey Measures: Content Knowledge.* The total scores from the multiple choice and open-ended responses were added together into a composite numerical score of teachers’ content knowledge, with a maximum possible score of 11. This composite score was then transposed into three descriptive levels of High, Medium, and Low content knowledge levels for each teacher (Table 4.4).

Table 4.4

**Content Knowledge: Pre-Survey Composite Scores and Levels**

<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>Composite Score</th>
<th>Level of Content Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mary</td>
<td>9</td>
<td>High</td>
</tr>
<tr>
<td>2</td>
<td>Sam</td>
<td>10.5</td>
<td>High</td>
</tr>
<tr>
<td>3</td>
<td>Jon</td>
<td>8.5</td>
<td>High</td>
</tr>
</tbody>
</table>

(continued)
Table 4.4

*Content Knowledge: Pre-Survey Composite Scores and Levels (continued)*

<table>
<thead>
<tr>
<th>#</th>
<th>Code Name</th>
<th>Composite Score</th>
<th>Level of Content Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Bob</td>
<td>9</td>
<td>High</td>
</tr>
<tr>
<td>5</td>
<td>Tom</td>
<td>9</td>
<td>High</td>
</tr>
<tr>
<td>6</td>
<td>Amy</td>
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<td>Medium</td>
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<tr>
<td>7</td>
<td>Cathy</td>
<td>8</td>
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</tr>
<tr>
<td>8</td>
<td>Sue</td>
<td>3</td>
<td>Low</td>
</tr>
<tr>
<td>9</td>
<td>Dave</td>
<td>0</td>
<td>Low</td>
</tr>
<tr>
<td>10</td>
<td>Patty</td>
<td>6</td>
<td>Medium</td>
</tr>
<tr>
<td>11</td>
<td>Mike</td>
<td>10</td>
<td>High</td>
</tr>
</tbody>
</table>

*Moon Formation Storyboard.* During the PD Program, every teacher developed their own storyboard with original text and/or drawings that captured their understanding of how the Earth’s Moon was formed. The final Moon Formation Storyboard scores, reflecting descriptive levels of either High, Medium, or Low levels of content accuracy for each teacher, are in Table 4.5.

Table 4.5

*Moon Formation Storyboard Content Knowledge Levels*

<table>
<thead>
<tr>
<th>#</th>
<th>Code Name</th>
<th>Level Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mary</td>
<td>High</td>
</tr>
<tr>
<td>2</td>
<td>Sam</td>
<td>High</td>
</tr>
<tr>
<td>3</td>
<td>Jon</td>
<td>High</td>
</tr>
<tr>
<td>4</td>
<td>Bob</td>
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<tr>
<td>5</td>
<td>Tom</td>
<td>High</td>
</tr>
<tr>
<td>6</td>
<td>Amy</td>
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</tbody>
</table>
(continued)
Table 4.5

*Moon Formation Storyboard Content Knowledge Levels (continued)*

<table>
<thead>
<tr>
<th>#</th>
<th>Code Name</th>
<th>Level Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Cathy</td>
<td>Low</td>
</tr>
<tr>
<td>8</td>
<td>Sue</td>
<td>Low</td>
</tr>
<tr>
<td>9</td>
<td>Dave</td>
<td>Low</td>
</tr>
<tr>
<td>10</td>
<td>Patty</td>
<td>Low</td>
</tr>
<tr>
<td>11</td>
<td>Mike</td>
<td>High</td>
</tr>
</tbody>
</table>

**Weather and Climate Concept Map.** During the opening of the PD Program teachers also engaged in a Concept Map task to activate their prior knowledge and understanding about the Earth’s weather and climate. The final Weather and Climate Concept Map scores, reflecting descriptive levels of either High, Medium, or Low levels of content accuracy for each teacher, are in Table 4.6.

Table 4.6

*Concept Map Content Knowledge Levels*

<table>
<thead>
<tr>
<th>#</th>
<th>Code Name</th>
<th>Level Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mary</td>
<td>High</td>
</tr>
<tr>
<td>2</td>
<td>Sam</td>
<td>Medium</td>
</tr>
<tr>
<td>3</td>
<td>Jon</td>
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<td>4</td>
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<td>5</td>
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<tr>
<td>6</td>
<td>Amy</td>
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<tr>
<td>8</td>
<td>Sue</td>
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<tr>
<td>10</td>
<td>Patty</td>
<td>Medium</td>
</tr>
<tr>
<td>11</td>
<td>Mike</td>
<td>Medium</td>
</tr>
</tbody>
</table>
**Content Knowledge Overall Scores.** Scoring from the pre-survey, moon formation storyboard, and concept map instruments, along with level of background coursework in the Earth and Physical sciences, were compiled together (Table 4.7) to provide an aggregate view of the measure of teacher’ baseline content knowledge from across each of these instruments. From these scores, a single, composite score of the level of a content knowledge was developed for each teacher (Table 4.8).

Table 4.7:

**Content Knowledge: All Scores**

<table>
<thead>
<tr>
<th>#</th>
<th>Code Name</th>
<th>Coursework Composite</th>
<th>Pre-Survey Composite</th>
<th>Moon Storyboard</th>
<th>Weather/Climate Concept Map</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>2</td>
<td>Sam</td>
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<td>High</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>3</td>
<td>Jon</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>4</td>
<td>Bob</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
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</tr>
<tr>
<td>5</td>
<td>Tom</td>
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</tr>
<tr>
<td>6</td>
<td>Amy</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>7</td>
<td>Cathy</td>
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<td>High</td>
<td>Low</td>
<td>Low</td>
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<tr>
<td>8</td>
<td>Sue</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>9</td>
<td>Dave</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>10</td>
<td>Patty</td>
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<td>Medium</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>11</td>
<td>Mike</td>
<td>High</td>
<td>High</td>
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</tr>
</tbody>
</table>

Table 4.8

**Content Knowledge Composite Score**

<table>
<thead>
<tr>
<th>#</th>
<th>Code Name</th>
<th>Level Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mary</td>
<td>High</td>
</tr>
<tr>
<td>2</td>
<td>Sam</td>
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<tr>
<td>3</td>
<td>Jon</td>
<td>High</td>
</tr>
<tr>
<td>4</td>
<td>Bob</td>
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</tbody>
</table>

(continued)
Table 4.8

Content Knowledge Composite Score (continued)

<table>
<thead>
<tr>
<th>#</th>
<th>Code Name</th>
<th>Level Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Tom</td>
<td>Medium/High</td>
</tr>
<tr>
<td>6</td>
<td>Amy</td>
<td>Low/Medium</td>
</tr>
<tr>
<td>7</td>
<td>Cathy</td>
<td>Low</td>
</tr>
<tr>
<td>8</td>
<td>Sue</td>
<td>Low</td>
</tr>
<tr>
<td>9</td>
<td>Dave</td>
<td>Low</td>
</tr>
<tr>
<td>10</td>
<td>Patty</td>
<td>Low/Medium</td>
</tr>
<tr>
<td>11</td>
<td>Mike</td>
<td>High</td>
</tr>
</tbody>
</table>

Understanding of Science Visualization (Sub-question 1B).

What do science teachers understand about science visualizations? Specifically:
1. Their conceptions of them?
2. What is the nature of their data and sources?

Teacher conceptions of science visualizations. An analytical perspective of the understanding that teachers had about scientific visualizations upon entry into this study was developed from multiple sources of data to address the question “Their conceptions of them?” First, teachers’ responses to the question, “What is a ‘scientific visualization’?” were coded against three distinctions in the conceptualization of visualization that were found to be important in the literature (Vavra et al., 2011); (1) visualizations as objects (code=O), (2) visualizations as introspective devices (code = IS), and (3) visualizations as interpretive action (code = IP). Teacher responses from the presurvey, and their assigned codes, are in Table 4.9.

Table 4.9.

Response Coding: What is a Science Visualization? (Pre)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Response</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>instead of putting science concepts into words making them pictures in your head or actual drawn or computer-generated pictures, videos, PowerPoints, animations</td>
<td>IP, O (continued)</td>
</tr>
</tbody>
</table>
Table 4.9.

Response Coding: What is a Science Visualization? (Pre) (continued)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Response</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>being able to form a <strong>mental image</strong> of the topic at hand. a scientific visualization is when you can take a scientific concept and associate an everyday concept with it, helping your understanding by comparison of the scientific concept.</td>
<td>IP</td>
</tr>
<tr>
<td>3</td>
<td>Seeing a picture of a scientific concept. I am guessing that you mean an image or video that conveys scientific information. a diagram used to represent a scientific concept or a 3-D model of a scientific concept</td>
<td>IP</td>
</tr>
<tr>
<td>4</td>
<td>Seeing a picture of a scientific concept. I am guessing that you mean an image or video that conveys scientific information. a diagram used to represent a scientific concept or a 3-D model of a scientific concept</td>
<td>IP</td>
</tr>
<tr>
<td>5</td>
<td>Something you can see to make a concept come to life. A model built to help someone understand a concept.</td>
<td>O</td>
</tr>
<tr>
<td>6</td>
<td>Science subject in a picture, video format. Seeing the world/situation through scientific eyes (with reasonable skepticism, curiosity, questioning)</td>
<td>O</td>
</tr>
<tr>
<td>7</td>
<td>Using visuals to dramatize content.</td>
<td>O</td>
</tr>
</tbody>
</table>

Key descriptors used by teachers in their open responses were identified (underlined in Table 5.12), extracted, and grouped by coding category to provide further insights into the ideas that teachers’ have about science visualizations (Table 4.10).
Table 4.10

Visualization Conception Descriptors by Category

<table>
<thead>
<tr>
<th>Objects</th>
<th>Interpretive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pictures, drawn or computer generated, videos, PowerPoints, animations</td>
<td>putting science concepts into [representations]</td>
</tr>
<tr>
<td>Picture</td>
<td>form a mental image of the topic at hand</td>
</tr>
<tr>
<td>Video format</td>
<td>Seeing a picture</td>
</tr>
<tr>
<td>Image</td>
<td>Seeing through scientific eyes</td>
</tr>
<tr>
<td>video</td>
<td></td>
</tr>
<tr>
<td>diagram</td>
<td></td>
</tr>
<tr>
<td>3-D model</td>
<td></td>
</tr>
<tr>
<td>Something you can see</td>
<td></td>
</tr>
<tr>
<td>A model built to help someone understand a concept.</td>
<td></td>
</tr>
<tr>
<td>visuals to dramatize content</td>
<td></td>
</tr>
</tbody>
</table>

Nature of visualization data and sources.

Key descriptors from teacher responses to the question, “Where do you think the data to make [this] visualization comes from?” were identified, extracted, and compiled for each of the five visualizations from individual interview transcripts. Descriptors were measured for frequency and presented for each visualization in separate groupings for Earth (see Table 4.11) and Space (see Table 4.12) topics.
### Table 4.11.

*Source Data for Scientific Visualizations: Earth*

<table>
<thead>
<tr>
<th>Viz 1: Global Clouds</th>
<th>Viz 3: Sea Ice</th>
<th>Viz 5: Ozone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Source</td>
<td>Frequency</td>
<td>Data Source</td>
</tr>
<tr>
<td>Satellite</td>
<td>11</td>
<td>Satellite</td>
</tr>
<tr>
<td>Computer enhancement (used in combination with satellite)</td>
<td>2</td>
<td>Ground-based observations and measurements (weather stations, snow records, etc.)</td>
</tr>
<tr>
<td>Computer Simulation</td>
<td>1</td>
<td>Computer generated or enhanced</td>
</tr>
<tr>
<td>Imagery</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4.12

*Source Data for Scientific Visualizations: Space*

<table>
<thead>
<tr>
<th>Viz 2: Earth’s Magnetic Field</th>
<th>Viz 4: Moon Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Source</td>
<td>Frequency</td>
</tr>
<tr>
<td>Satellite or spacecraft</td>
<td>5</td>
</tr>
<tr>
<td>Computer generated</td>
<td>2</td>
</tr>
<tr>
<td>Computer Simulation</td>
<td>2</td>
</tr>
<tr>
<td>Computer, computer generated (non-specific)</td>
<td>2</td>
</tr>
<tr>
<td>Telescope</td>
<td>2</td>
</tr>
<tr>
<td>NASA</td>
<td>1</td>
</tr>
</tbody>
</table>
Instructional Use of Visualizations (Sub-question 1C).

What level of data visualizations use do teachers report in their science instruction?

Table 4.13 shows teachers’ reported usage of visualizations that were similar to the types of visualizations used in this study. Reported sources for visualizations were extracted, grouped by category, and measured for frequency. Results were further sub-divided (Table 4.14) into Earth and Space categories due to differences that emerged between these two content areas during the analysis.

Table 4.13

Teacher Use of Scientific Visualizations

<table>
<thead>
<tr>
<th>Viz</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Global Clouds</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>2: Earth’s Magnetic Shield</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>3: Sea Ice*</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>4: Our Moon</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>5: Global Ozone</td>
<td>0</td>
<td>11</td>
</tr>
</tbody>
</table>

*One non-response

Table 4.14

Teacher Reported Sources for Visualizations: Earth vs. Space

<table>
<thead>
<tr>
<th>Source</th>
<th>Frequency</th>
<th>Source</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Educational Material (video)</td>
<td>3</td>
<td>Weather map</td>
<td>4</td>
</tr>
<tr>
<td>United Streaming (online)</td>
<td>1</td>
<td>Weather visualizations (internet)</td>
<td>2</td>
</tr>
</tbody>
</table>

(continued)
**Table 4.14**

*Teacher Reported Sources for Visualizations: Earth vs. Space (continued)*

<table>
<thead>
<tr>
<th>Space Content</th>
<th>Earth Content</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Source</strong></td>
<td><strong>Frequency</strong></td>
</tr>
<tr>
<td>Video (online, NASA, SOHO) Data-driven</td>
<td>1</td>
</tr>
<tr>
<td>Visual Representation (two dimensional, static) of magnetic field</td>
<td>1</td>
</tr>
<tr>
<td>Animation</td>
<td>1</td>
</tr>
</tbody>
</table>

**Question 2: Classroom Implementation**

When supplied with a set of data visualizations, how do teachers integrate and implement them into their domain-specific instruction?

The case selection process resulted in identifying two teachers that taught the same grade and had the same level of technology available in their classroom, as well as having similar technological expertise (see Table 4.15). Despite these similarities, they offered a unique story of contrasts. One teacher was a new teacher with a high level of content knowledge, and the second teacher was a seasoned classroom teacher who happened to be in her first-year teaching science and had a Low level of science content expertise.

The following two cases explore the experience from initial exposure to instruction for two teachers, Patty and Bob. Each case offers a story of instructional implementation in three acts—initial visualizations exposure and PD program experience, curricular integration of visualizations, and finally classroom implementation.
Table 4.15

*Case Study Comparison Across Key Demographics*

<table>
<thead>
<tr>
<th>Background coursework: Earth and Physical Sciences</th>
<th>Case 1: Patty</th>
<th>Case 2: Bob</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content Knowledge</td>
<td>Low/Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Years teaching</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Years teaching science</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Certification: Grades</td>
<td>K-6</td>
<td>5-9</td>
</tr>
<tr>
<td>Science Certification</td>
<td>Not science</td>
<td>Biology/Life Science, Earth Science, Astronomy, Geology</td>
</tr>
</tbody>
</table>

**Case 1: Patty**

Patty has been teaching for 10 years and was teaching 5th and 6th grade at a suburban Catholic school in a Midwestern city when she participated in this study. She had some previous exposure to teaching science when she taught kindergarten, first and second grade, but when asked about it, she explains, “I've always been a math person. I taught social studies and geography. This is my first year really teaching science.” Her content knowledge measured Low/Medium using the methods of this study.

Before participating in the PD program, Patty was personally comfortable with technology and had access to smartboard and projection technology in her classroom that she uses to display videos and interactives on a large screen for group viewing during her instruction. She is comfortable with searching and finding visual representations, “on the fly” from the Internet, even during her instruction:
Sometimes when I'm teaching and I get that “cricket moment” when they're just not getting it, they don't see it, they don't understand it, and it's like, “Oh, if you could just see this,” what I'm talking about, you know maybe it would bring it closer to your understanding. So those moments…I'll stop and I'll go to the Internet and I'll try to search for one real quick to see if I can get one.

Patty had limited exposure to scientific data visualizations before the PD program and she had never used anything like them in her instruction. After being exposed to the visualizations, Patty started the group discussion in the PD program by immediately considering them as models:

I guess I just thought of it as where you look at things scientifically, but it's like visualizing a model or thinking of something critically. So, in its most simplistic form, is it just a model?

The majority of her questions throughout the PD program was focused on deepening her own connections and understanding of the meaning and information that the visualizations represented, particularly with respect to limitations in the data and visuals displayed.

For Patty, curriculum integration began as soon as she was exposed to the visualizations. She regularly shifted to “teacher speak” throughout the PD program, where she would talk as-if she were addressing her students directly. When asked to make her own narration for her first visualization exposure, Global Clouds, she shifted to the perspective of an imagined classroom implementation:

I would point out where they see clouds and where they don't see clouds.

And I would have somebody pick a spot where they are seeing clouds and keep watching it. Do you still see clouds? Do you see a pattern happening in the clouds? Or pick a spot
that doesn't have clouds. Do you see clouds forming? Do you ever see clouds forming?

Why do you think that is?

When asked to consider the visualizations in the study for instructional use, Patty moved further into curricular integration to also consider supplemental materials she would use to scaffold student engagement with the visualization:

You could talk about the landforms. Have the kids find a map of landforms. It would be good if you could have like have a black line master of this precise map layout, with land forms, or have the kids put their own landforms, and then see what weather patterns are happening around what landforms. Like you got deserts here and deserts here, and if there's an obvious lack of clouds.

Patty felt that scientific visualizations held the potential to elicit questions from students about their own thinking, rather than tell them a finished story. Here she describes why she finds instructional value in these types of visualizations:

[They] make [a concept] come to life. Makes them [students] realize that it's something more than just something they see in their textbooks. If you're just putting up flat images and static images, you've just basically blown up what’s in their textbook and it's nothing different. And I think it excites them.

But Patty recognizes that these kinds of visualizations have their place and are not the solution to engaging her student in all phenomena:

If it's something that I can show them in class I'd rather them be hands-on and touch it, feel it, smell it, whatever. Growing of crystals, for instance. I can show a visualization of time lapse of a crystal growing, but that's not as cool as actually growing a crystal and having them actually observe it, which is what we did…. Things that are too far away,
too far in the past, that they can't physically experience, that's when visualization is better because it makes it seem like they're experiencing it.

For her own instruction, Patty selects two of the visualizations from this study, Global Clouds and the Earth’s Magnetic Shield, to use in two of her 6th grade classes. In her first implementation, Patty uses the produced version of the Global Clouds visualization for her geography class. She explains:

I didn’t want to spend a lot of time in geography on the science of weather, I wanted to get to, “What will this do to the culture? How does this affect cultural development?”…

That’s why I used the narration [produced version], because I wanted to get there quicker.

Had I been focusing on the science of weather, I think I would have used the non-narrated one and asked them, “What do you see?... Where do you see the jet stream?”…

But I used the narrated ones so that they could see the passage of time.

Patty’s second visualization implementation was observed by the researcher. She selected the visualization of the Earth’s Magnetic Shield that was non-narrated (the “raw” version) to use in her 6th grade Earth science class. She embedded it in a unit on the solid structure of the Earth, referencing a specific chapter in her textbook that she was working through. The progression of concepts that led into the usage of this visualization had begun with plate tectonics and moved to the Earth’s interior structure and the core of the Earth. The Earth’s magnetic field was introduced in the context of the Earth’s core and its role in the generation of the magnetic field.

Additionally, Patty had shared evidence with her students about the Earth’s early magnetic field in the form of images of “striping on the bottom of the sea that shows the reversal of the magnetic field that’s happened.” In this way, Patty felt that she had “set the stage” for the
visualization, and that is was a, “perfect time to talk about why do we have a magnetic field. Don’t just tell me about it and forget it.”

Patty’s classroom is set-up with desks paired into groupings of four. She begins the implementation at the start of the class period by writing a question on the smart board in the front of the classroom, “Why do we have a magnetic field? What’s its purpose?” She asks students to share their ideas, and she accepts and probes those who provide superficial answers. Students seem comfortable to offer their ideas in the classroom culture that Patty has developed. Patty then opens the Earth’s Magnetic Shield (raw) visualization and projects in on the large screen at the front of the room. The screen is a little lower than usual, which seems to make it more “accessible” to students who want to go up and look closer or point something out. As soon as it becomes visible as an image on the screen, excited exclamations of, “Yes!” come from the students, and one student yells, “We are in SPACE!” Patty doesn’t try to quiet them down, rather she calmly lets the initial wave of excitement pass and then seems to use it to propel the conversation forward.

Patty orients the students to what they are going to be watching and frames the goal of the viewing, “We are going to watch this raw, which means it has no sound or text on it. See if you can answer the purpose of the magnetic field.” As soon as she starts playing the visualization, students start saying, “Wow! Cool! It looks like a comet!” When the Earth emerges visibly from inside the magnetic field, one student exclaims, “It’s us!” There are multiple excited discussion threads occurring among the students, but they are all engaged and watching as Patty lets the visualization play through to the end. As soon as it ends, Patty resets it to the beginning and starts it again. This second time through, Patty pauses the visualization anytime a new feature or aspect of the system appears onscreen. She goes to the screen and points out features
(i.e. a magnetic field line or the solar wind or the Earth’s direction and poles, etc.) and asks the students many questions like, “What are those things going by [points to solar wind]?” She continues to probe them for their ideas and allows the class to collectively generate a narrative on their own. Patty is facilitating the viewing and eliciting students’ ideas about what they are seeing, not narrating it for them or telling them what they are seeing. The students have lots of ideas, but they really focus in on the visual of the bow shock that forms where the solar wind is striking the Earth’s magnetic field. They wonder what it might be. Students share their ideas one after the other, and Patty encourages them and teases out those ideas that are going “in the right direction.” One student believes it might be the ozone hole. Another connects the bow shock to a speeding asteroid travelling through the atmosphere [another phenomenon with a similar shape].

One of the highlights of the class discussion came when one student said that the solar wind being deflected by the magnetic field looked, “like rain striking a car windshield.” This answer resonated with Patty and she asked the student to come to the screen and point out exactly what they were seeing and why it looked like rain to them. After the student pointed it out, Patty went to the screen and followed the same pointing motions of the student but began to apply the scientific meanings to the phenomenon that they were seeing. She described that the charged particles from the Sun were deflected when they entered into the magnetic field, and their path took them along the field lines into the poles, where they interacted with the atmosphere to produce the glowing colors of the Aurora. The class period came to a close with a sense that they had all come to a collective narration for the visualization.

Patty reflected on her instruction in a semi-structured interview immediately following the implementation. When asked to describe her approach to asking students questions about the visualization, she described her experience with various approaches, and why she feels that the
approach she took in this lesson—open probing of what students are seeing—is better for classroom discussion and provides her with a rich formative assessment:

If you are looking for— and I've been both of those teachers-if you're looking for the right answer to this is what it is, and some kid says, “No, this is what I see, I see a comet” “No, that's not a comet.” Then they may be less likely to continue telling them versus if you go, “It does kind of look like a comet. Why do you think it's a comet?” Then they may be more likely to see that it's okay to give a wrong answer.

For one thing, when it comes to something like this, if you're really trying to get the kids to tell the [“right”] story, what I could've done is sat down and said, “Okay, we're watching a video,” and watch the produced version and then asked, “What did you learn from that?” I've done that before. You don't get the kind of response, you don't get the kind of input, versus the way, “Okay, what did you just see? What is happening here?” If you're really trying to get them to discover it then you kind of have to accept anything, and ask them, “Why did you think that?”

Because to me the question that they hate to answer is the most important answer, “why did you see that? Where was your thinking that led you to believe that that's what this was?” Because that's going to tell me whether they're totally tangential off on something else, or if they're just coming at it through the back door, because a wrong answer might not be as wrong as you think it is. It may be the wrong response, but they have the right understanding, they just don't know how to get there. So, to ask the question, “Why do you think that?” and “Tell me what you saw,” to me tells me more about where they are. So that's going to help me guide them. That's more of a formative assessment.
Finally, when asked to reflect on her choice to use the “raw” version of the visualization, and not the produced one, she says that this decision greatly impacted her approach to using it. If she only had the produced version that included a narration and specific storyline, she would have, “treated it more like a video.” But by using the raw version of the visualization:

We had to provide our own narration. We had to tell the story. There was nothing there to help us. There was no music. There was no… word, there was nothing, other than the picture, which begs the question, what is that? And that provides the fodder for discussion. Because videos, and narrated version, spoon feed you the information, whereas the naked narration, or the visualization, you have to figure it out. And that's really what you want them to do. It's an investigation without getting your hands dirty. And science is all about, gee that's interesting, why does that happen?

**Case 2: Bob**

Bob is in his second year of teaching 6th grade at an urban public school in a Midwestern city when he participated in this study. His content knowledge measured High using the methods of this study, and he was certified to teach in four different science content areas.

Before participating in the PD program, Bob was very comfortable with technology, and was in fact the technology specialist for his school and often in trainings for that role. He had access to a projector and screen in his classroom that he uses to display Power Point presentations and to stream videos in his classroom instruction, which he does daily. He stated that he was comfortable searching and finding visual representations on the Internet, with his preferred formats being pictures and videos.

Going into the PD program, the instructional practices that Bob described were “cookbook” lab activities that would “show” a student how to explore a phenomena or concept.
When asked to describe how he would address two different student misconception, he responded with a lab procedure that he followed. One example follows:

We do a greenhouse effect lab using heat lamps over covered and uncovered jars. The procedures are as follows: 1. Begin with the light turned off and both containers uncovered. 2. Each container should have one thermometer in it. 3. Leaving the thermometer in it, carefully and completely cover one container with the plastic wrap. 4. Record the temperature of the thermometers in degrees Celsius on the table below under “Starting Temperature”. 5. Turn on the light and make sure both containers are getting the same amount of light. KEEP the light on and the container covered for the entire 5 minutes. 6. Two people in your group need to watch the clock and every minute two other people need to read the thermometers and share the readings with the group. 7. EVERYONE records the temperatures in their charts. 8. After 5 minutes, turn the light off and watch the thermometers in both containers for a minute. We also "act out" the greenhouse effect by having the students play the different parts of the light, heat, and the greenhouse gases. We also have reinforcement worksheets and videos we use.

Bob reported limited exposure to scientific data visualizations before the PD program and he had never used anything like them in his instruction. After being exposed to the visualizations, he was asked to “talk through” them and pretend that he was talking to his students and offer his own narration. The words that he used to describe his instructional practices throughout all of his visualization narrations and the PD program, were, “show students,” and, “can talk about.” When asked about the concepts that these visualizations could be used teach, he almost always responded in single words or phrases (i.e., wind patterns, Coriolis effect, seasons, etc.).
At the end of the PD program, Bob reported that he planned to use two of the visualizations, “Sea Ice to show global climate change and human impact. Our Moon – to show how moon formed before we talk about phases of moon.” Bob felt that his students’ response to the visualizations would be that, “They will enjoy [them]. They will keep their attention.”

Bob implemented only one of the visualizations in the study, Our Moon, but he used both the raw and produced versions of this visualization. This was difficult for him, due to a rather rigid curriculum that his school was already implementing for a grant—making Bob have to incorporate the visualizations, “on top of anything else that I did, and that put me back on my whole schedule for everything that I’ve done this year.”

Bob used the two versions, both raw and produced, of Our Moon (viz., 4). He integrated them into the beginning of a unit on the phases of the Moon and eclipses. He explains:

It was pretty much to introduce the Moon and how it forms. Most of the students have never heard how the Moon forms or how it got there, so that was just a theory I try to introduce to show them how the Moon formed.

Bob’s visualization implementation was observed by the researcher. Bob’s classroom is set up with the desks in rows from front to back, with the board and screen at the front of the room. Bob stands in the front of the room and begins the class by asking students to share something that they already know about the Moon. Their answers are constrained mainly to facts; it revolves around the Earth, it has craters, it has eight phases, etc. Bob does not probe answers further, but accepts them and intersperses, “Eyes on board!” throughout, in response to the student engagement. After a handful of students have shared their ideas, Bob shows the raw version of the visualization about the Moon formation. He provides no framing questions or
comments on what they are going to be viewing. The students are silent as the visualizations play. The following dialogue outlines what happened next in the classroom:

    Bob: What did you see?
    Students: I saw a meteorite go around the earth. I saw an object the size of Mars hit the early Earth. Do the meteorites go that fast?
    Bob: I’m not answering any questions, I want to know what you saw
    Students: Saw the rocks hitting the Earth. It looked like magma.
    Bob: Now I am going to play another video, I am going the be reading the text to you.
    [Plays the produced, narrated version of Our Moon]
    What did it show?
    Students: That Mars and Earth collided. Chunks of Earth flew off
    [Bob replays the video and stops it at certain points. Pausing at the point of collision in the video…]
    Bob: Why didn’t the stuff just keep going?
    Students: Gravity
    Bob: That’s the theory of how our moon formed

At the conclusion of the second viewing of the produced visualization, Bob moves into an all-class assessment task. He asks a series of questions that are in a fill-in-the-blank format. For example, “We all know that the moon [insert answer] around the Earth.” He follows this by providing a few different scenarios and asks students to remember the names of the phenomena (i.e. eclipses, moon phases). Bob then transitions to the next topic in the unit, the phases of the Moon. He asks students to write down what is on the board into their science notebooks. It says, “The Moon is reflecting the light from the Sun.” He then moves into a demonstration of the
different phases of the Moon that he alone does at the front of the room with a flashlight and a ball. When he gets to the demonstration of a Full Moon, one of the students says, “There was a full moon last night!” And a second student chimes in, “I saw the Sun and the Moon during the day once!” Students are starting to share their Moon experiences with each-other and the room begins to buzz. Bob quickly responds, “We are talking about Moon phases right now, so back to that.” The class quiets down and he moves into another round of fill-in-the-blank questioning, this time around the Moon phases. The formation of the Moon is not mentioned again for the remainder of the class period.

When Bob reflected on his instruction in a semi-structured interview that followed the implementation, he described what he did almost procedurally:

Well I pretty much just told them that I had a video for them to watch and I played it and then I asked them, what did they see? What were their observations? What did they think they saw? And got that. And then I played the completed version and that's how I introduced the formation of the Moon and went from there. When asked about his approach to using the raw visualization first, followed by the produced version, he talked about the progression of first probing students about what they see, followed by showing them the “correct” theory and asking them what changed in their understanding. In his own words, he uses instructional practices descriptors that include, “talking to,” and, “telling,” mirroring words he used during the initial visualization exposure interviews at the beginning of the study:

I liked it because of the unfinished, or the raw, and then the finished one with the words. It was a good way to see what they were thinking when they saw it because normally we just show a video or a clip and it's talking to the kids and its telling them
what's going on, but I like seeing the unfinished version, seeing what they thought, and then going from there, playing the completed version and seeing if their thoughts had changed.

Bob expressed interest in using more data visualizations in his instruction moving forward. He sees a value-added for his instruction in showing students things that they cannot easily see any other way. He sums up his view of the value of visualizations for his instruction, and his intended usage of them moving forward:

The way I like to use the visualizations I could see them mainly I guess, for my use, to be more of a kind of an introductory, kind of like I did with the Moon. Kind of introducing, we were talking about moon phases, but I needed to introduce the moon somehow and I just say, okay here we go with moon phases. I liked how I used it to introduce this is where we think we got the moon from. They got to watch it. We discussed it, that's a moon and we went from there.

**Question 3: Teacher Impacts and Needs**

This research question examined the impact that exposure to, and instruction with, scientific visualizations had on the teachers by exploring five sub-questions that target how teachers’ content knowledge and understanding of science visualizations changed, as well as the questions, needs and recommendations that emerged that are relevant to the focus of this study. Results of analysis for each of these sub-questions follow in dedicated sections.

A. What was teachers’ change in content knowledge?
B. What was their change in understanding of visualizations?
C. What questions did teachers have about visualizations?
D. What resources and supports did they report needing or wanting?
E. What recommendations did they have for the PD program?
Change in Teachers’ Content Knowledge (Research Ques. 3A). The Post-Survey included nine items, in multiple choice and open-response formats, that together informed the measure of the participants’ baseline content knowledge at the closing of participation in the study. Results of analysis for each of these two types of questions follow.

Multiple-choice questions. An overall score for the six multiple choice items in the post-study was obtained by adding together all individual item scores, with the maximum possible score being 6 (see Table 4.16).

Table 4.16

Post-Survey Content Knowledge Multiple Choice Scores

<table>
<thead>
<tr>
<th>Code Name</th>
<th>11.13</th>
<th>11.14</th>
<th>11.15</th>
<th>11.20</th>
<th>11.21</th>
<th>11.22</th>
<th>Total Score (max=6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Mary</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>2 Sam</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>3 Jon</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>4 Bob</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>5 Tom</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>6 Amy</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>7 Cathy</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>8 Sue</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>9 Dave</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>10 Patty</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>11 Mike</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>

Open-response questions. The remaining content knowledge data from the post-survey resulted from three open-ended response items. Teachers’ combined score for these items, with a possible maximum of 3, are listed in Table 4.17.
Table 4.17

*Post-Survey Content Knowledge Open-Response Scores*

<table>
<thead>
<tr>
<th>#</th>
<th>Code</th>
<th>Name</th>
<th>11.16</th>
<th>11.18</th>
<th>11.19</th>
<th>Total Score (max = 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11.16</td>
<td>Mary</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>11.18</td>
<td>Sam</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>11.19</td>
<td>Jon</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Bob</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Tom</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Amy</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Cathy</td>
<td>0</td>
<td>1</td>
<td>0.5</td>
<td>1.5</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Sue</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>Dave</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>Patty</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>Mike</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

**Combined content knowledge scores.** Scores for the multiple choice and open-ended responses were added together to provide an overall numerical score of teachers’ content knowledge, with a maximum possible score of 9. This overall score was then compared to the scores of the same items from the pre-study survey, and the difference from pre-post was calculated to provide a measure of teachers’ change in content knowledge from the beginning to the end of the study (see Table 4.18).
Table 4.18

*Pre- & Post-Content Knowledge: Overall Scores and ΔPre-Post*

<table>
<thead>
<tr>
<th>#</th>
<th>Code Name</th>
<th>Total Score (max = 9)</th>
<th>Change in Content Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mary</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Sam</td>
<td>8.5</td>
<td>-0.5</td>
</tr>
<tr>
<td>3</td>
<td>Jon</td>
<td>7.5</td>
<td>0.5</td>
</tr>
<tr>
<td>4</td>
<td>Bob</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Tom</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Amy</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>Cathy</td>
<td>7</td>
<td>-0.5</td>
</tr>
<tr>
<td>8</td>
<td>Sue</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Dave</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>Patty</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>Mike</td>
<td>8</td>
<td>1</td>
</tr>
</tbody>
</table>

Average: 6.2 (Pre) 6.8 (Post) 0.6 (Δ)

**Change in visualization understanding (Research Ques. 3 B).**

Changes in teachers’ understandings about scientific visualizations were probed in the post-survey using the same open-response item used in the pre-survey, “What is a ‘scientific visualization’?” Responses were coded against three distinctions in the conceptualization of visualization that were found to be important (Vavra et.al., 2011). Teacher responses from the pre-survey, and their assigned codes, are in Table 4.19. Finally, the measure of teachers’ pre- and post-understandings of visualizations were compiled into a table (Table 4.20), and any changes were described in a dedicated column. No change was denoted by a “0.”
Table 4.19

Response Coding: What is a Science Visualization? (post)

<table>
<thead>
<tr>
<th>Participant</th>
<th>Response</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A method of taking an abstract concept, global scale or costly inefficient model to &quot;life&quot; with data, graphics, or animation</td>
<td>IP</td>
</tr>
<tr>
<td>2</td>
<td>visual representation of info being taught</td>
<td>O</td>
</tr>
<tr>
<td>3</td>
<td>being able to view a situation or example of something to do with science</td>
<td>IP</td>
</tr>
<tr>
<td>4</td>
<td>Some type of video that uses real data to show a scientific concept.</td>
<td>O</td>
</tr>
<tr>
<td>5</td>
<td>The visual expression of scientific data</td>
<td>O</td>
</tr>
<tr>
<td>6</td>
<td>Visual of collected data pertaining to scientific concepts</td>
<td>O</td>
</tr>
<tr>
<td>7</td>
<td>A display of data collected</td>
<td>O</td>
</tr>
<tr>
<td>8</td>
<td>a video clip explaining a scientific idea</td>
<td>O</td>
</tr>
<tr>
<td>9</td>
<td>Real DVD of a certain science subject, space, sea</td>
<td>O</td>
</tr>
<tr>
<td>10</td>
<td>A way to show difficult concepts visually</td>
<td>IP</td>
</tr>
<tr>
<td></td>
<td>computer generated experiences</td>
<td>O</td>
</tr>
<tr>
<td>11</td>
<td>When scientific data and concepts are presented using animation and computer graphics to illustrate the data or concepts.</td>
<td>IP</td>
</tr>
</tbody>
</table>

Table 4.20

Teachers’ Understandings of Science Visualization: Pre-, Post- & ΔPre-Post

<table>
<thead>
<tr>
<th>Subject</th>
<th>Pre</th>
<th>Post</th>
<th>Δ Pre-Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IP &amp; O</td>
<td>O</td>
<td>- IP</td>
</tr>
<tr>
<td>2</td>
<td>IP</td>
<td>O</td>
<td>IP -&gt; O</td>
</tr>
<tr>
<td>3</td>
<td>IP</td>
<td>IP</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>IP</td>
<td>O</td>
<td>IP -&gt; O</td>
</tr>
<tr>
<td>5</td>
<td>O</td>
<td>O</td>
<td>0</td>
</tr>
</tbody>
</table>

(continued)
Table 4.20

*Teachers’ Understandings of Science Visualization: Pre-, Post- & ∆Pre-Post (continued)*

<table>
<thead>
<tr>
<th>Subject</th>
<th>Pre</th>
<th>Post</th>
<th>∆ Pre-Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>O</td>
<td>O</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>O</td>
<td>O</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>O</td>
<td>O</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>O</td>
<td>O</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>IP</td>
<td>IP &amp; O</td>
<td>+ O</td>
</tr>
<tr>
<td>11</td>
<td>O</td>
<td>IP &amp; O</td>
<td>+ IP</td>
</tr>
</tbody>
</table>

Key descriptors used by teachers in their open responses were again identified, extracted, and grouped by coding category to provide further insights into the specific ideas that teachers’ have within each of these categories of science visualization conceptualizations. Finally, the results of this analysis were placed in a table (see Tables 4.21 and 4.22) alongside the same analysis from the Pre-Survey responses, to provide insights into changes in teachers’ conceptions that could have resulted from their participation in this study.

Table 4.21

*Pre- & Post- Visualization Conception Descriptors: Interpretive*

<table>
<thead>
<tr>
<th>Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>• putting science concepts into</td>
<td>• being able to view a situation or</td>
</tr>
<tr>
<td>[representations]</td>
<td>example of something to do with science</td>
</tr>
<tr>
<td>• form a mental image of the topic at</td>
<td>• A way to show difficult concepts</td>
</tr>
<tr>
<td>hand</td>
<td>visually</td>
</tr>
<tr>
<td>• Seeing through scientific eyes</td>
<td>• When scientific data and concepts</td>
</tr>
<tr>
<td>• Seeing a picture</td>
<td>are presented</td>
</tr>
<tr>
<td></td>
<td>•</td>
</tr>
</tbody>
</table>
Table 4.22

Pre- & Post- Visualization Conception Descriptors: Objects

<table>
<thead>
<tr>
<th>Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Pictures, drawn or computer generated</td>
<td>• A method of taking an abstract concept to &quot;life&quot;</td>
</tr>
<tr>
<td>• videos,</td>
<td>• visual representation of info</td>
</tr>
<tr>
<td>• PowerPoints,</td>
<td>• type of video to show concept</td>
</tr>
<tr>
<td>• animations</td>
<td>• visual expression of scientific data</td>
</tr>
<tr>
<td>• Image</td>
<td>• Visual of collected data pertaining to scientific concepts</td>
</tr>
<tr>
<td>• video</td>
<td>• A display of data collected</td>
</tr>
<tr>
<td>• diagram</td>
<td>• a video clip explaining a scientific idea</td>
</tr>
<tr>
<td>• 3-D model</td>
<td>• Real DVD of a certain science subject, space, sea</td>
</tr>
<tr>
<td>• Something you can see</td>
<td>• computer generated experiences</td>
</tr>
<tr>
<td>• A model built (sic) to help someone understand a concept.</td>
<td>• animation and computer graphics</td>
</tr>
<tr>
<td>• Picture</td>
<td></td>
</tr>
<tr>
<td>• video format</td>
<td></td>
</tr>
<tr>
<td>• visuals to dramatize content</td>
<td></td>
</tr>
</tbody>
</table>

Teacher questions about visualizations (Research Ques. 3C).

Teachers had multiple opportunities to ask questions throughout the study. Two main data sources for teacher questions were the Individual Interview Transcripts and the PD Program transcripts. Both were analyzed to identify patterns to the types and frequency of teachers’ questions about the visualizations used in this study. Results of analysis for each of these two data sources are in the following sections.

Questions from individual visualization interviews. During the Individual Visualization Exposure Interview, teachers were asked what questions they had about each of the five
visualizations. Their responses provide a rich source of insight into their thinking immediately following their first viewing the raw visualizations. Questions were compiled from interview transcripts, and emergent coding was used to develop descriptive categories for the types of questions teachers asked, with an initial list of five categories ultimately splitting into seven, distinct categories. These categories were defined and given unique codes (Table 4.23) and samples of coded responses were selected to clarify boundary cases of the coding (Table 4.24).

Table 4.23

<table>
<thead>
<tr>
<th>Code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display (D)</td>
<td>• Specific reference to on-screen visuals, with no mention of attempting to connect them to specific meaning (includes general “what is it” questions)</td>
</tr>
<tr>
<td>Meaning (M)</td>
<td>• Seeking to make meaning of the visuals on the screen and connecting it to prior knowledge. [Boundary: questions of meaning that do not go “beyond the visuals”]</td>
</tr>
<tr>
<td>Time (T)</td>
<td>• Questions of time period represented</td>
</tr>
<tr>
<td>Conceptual (C)</td>
<td>• Asking conceptual questions about the meaning or content (referent). [Boundary: questions that go “beyond the visuals” and show evidence of connection to a mental model that is accurate but seeking further details/meaning through a cognitive process.]</td>
</tr>
<tr>
<td>Nature (N)</td>
<td>• Asking about the nature of the data/source (includes mention or concern of bias in data exclusion)</td>
</tr>
<tr>
<td>Product (P)</td>
<td>• Asking about the format/product/production of the viz (as a media object)</td>
</tr>
<tr>
<td>Instructional (I)</td>
<td>• Asking about instructional application or usage</td>
</tr>
</tbody>
</table>

The frequency of each type of question was measured for each of the five visualizations, and the total number of questions asked about each of the visualizations was calculated (Table 4.25). This number could be greater than the number of teachers in the study because many of the teachers asked more than one question during their interview.
Table 4.24

*Code Boundaries for Types of Teacher Questions about Visualizations*

<table>
<thead>
<tr>
<th>Sample Response</th>
<th>Code Applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>• I would probably want to know if these cloud patterns are a characteristic elevation or altitude.</td>
<td>Conceptual</td>
</tr>
<tr>
<td>• What season it is?</td>
<td>Meaning Making</td>
</tr>
<tr>
<td>• Am I correct? What is it? [Refers back to her initial answer of clouds being displayed.]</td>
<td>Wants to know what visuals represent = Display</td>
</tr>
<tr>
<td>• I just saw clouds. I didn’t…I’m thinking that you see precipitation and other things. I don’t know if it is because of the zoom.</td>
<td>Wants additional information/parts of the model to be included. Code as Making Meaning.</td>
</tr>
<tr>
<td>• Is anything else missing? Did they take anything off just to show, you know, did they filter something out?</td>
<td>Seeking boundary of data included in the viz, coded as Nature of Data</td>
</tr>
<tr>
<td>• Where’d they get it, cause it’s a nice one. (Source of video as a product)</td>
<td>Product</td>
</tr>
</tbody>
</table>

Further analysis provided a deeper look into the kinds of questions that teachers most frequently had about the two different types of visualizations in this study, Earth and Space. The percentage for each question type of the overall questions was calculated, and results were grouped by Earth and Space topics (Table 4.26) to surface any difference in questioning patterns between these two different visualization types and topics.

Table 4.25

*Types of Questions Asked for Visualizations: Frequency and Total*  

<table>
<thead>
<tr>
<th>Visualization</th>
<th>D</th>
<th>M</th>
<th>N</th>
<th>T</th>
<th>P</th>
<th>I</th>
<th>C</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Global Clouds</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>2 Magnetic Field</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>3 Sea Ice</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0*</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>4 Moon Formation</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>5 Ozone</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>0*</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>15</td>
</tr>
</tbody>
</table>

*The raw visualizations 3 and 5 had visible date labels on them, due to production limitations, which removed the need for teachers to ask about the time/date period.*
Table 4.26

*Questions by Type: Each Visualization and Overall Average*

<table>
<thead>
<tr>
<th>Question Type</th>
<th>Earth</th>
<th>Space</th>
<th>Average %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display</td>
<td>Viz 1</td>
<td>Viz 3</td>
<td>Viz 5</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>21</td>
<td>40</td>
</tr>
<tr>
<td>Meaning</td>
<td>8</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>Nature</td>
<td>16</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Time</td>
<td>37</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Product</td>
<td>0</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Instruction</td>
<td>0</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Concept</td>
<td>8</td>
<td>14</td>
<td>0</td>
</tr>
</tbody>
</table>

*Questions about visualizations during PD program.* The PD program included substantial time for group discussion for each of the five visualizations, to provide teachers an opportunity to make meaning from them and probe the concepts, data sources and underlying models that they represent. These discussions among teachers, and with the PD leader, were rich with examples of questions and issues that teachers repeatedly expressed across multiple PD sessions. To identify these themes in teacher questions, transcripts of the PD programs were analyzed. Key themes that were identified are described in the following sections.

*Struggling to make meaning from visualizations.* The entryway into understanding what any visualization is representing is making meaning from the visual display, connecting a color, line or pattern to a deeper concept that the viewer knows. The barrier to this understanding, particularly with data visualizations that can have visual artifacts in the data, often arise from not knowing what “matters” and what is just an imaging problem resulting in a “glitch” in the data that becomes visible in the raw visualization.
In this first example, teachers are viewing the raw Global Clouds visualization when one of them notices the regular pattern of light and dark sweeping across the underlying Earth surface, seemingly below the clouds that are the main focus of the visualization. The following discussion highlights their consideration of the meaning of this pattern (Figure 5.5):

Teacher 1: I couldn’t tell what this dark…see how the continents are getting darker? I don’t know.

PD Leader/Researcher: When you say darker [See Figure X] are you saying this darkness sweeping across regularly?
Teacher 2: I didn’t notice that

Teacher 3: I didn’t notice that either.

PD Leader/Researcher: See how it passes over the Sahara? [points]

Teacher 2: Is that a satellite, maybe? Going underneath another satellite, like a shadow or something?

In another example, teachers are viewing the raw Sea Ice visualization when they ask about the circular pattern visible, and unchanging, in the center of the sea ice data (Figure 5.6). This artifact in the data, caused by the satellite not providing data at those points, and the subsequent decision by the visualization designer to represent this lack of information as a single color that matches the sea ice data, causes considerable confusion among the teachers about what it represents:

Teacher 1: So, it’s a blind spot?

PD Leader: A lot of people think that its presence is telling us something scientifically, when actually it is just an artifact of the data that the satellite causes.

Teacher 1: So, is there no way…is there a reason why they don’t get rid of it?

PD Leader: But if they got rid of it, it would just look like a hole.

Teacher 1: Can they fill it in?

PD Leader: They filled it in with plain white.

Teacher 1: But when they fill it in like that, it makes it look like something significant. Whereas instead of just making it…

Teacher 2: Maybe they should have swirled it
Teacher 3: Just tell them, “That represents the North Pole.”

PD Leader: This is where the symbols and how you represent something really matter. They never pointed it out…

Teacher 1: Exactly, pay no attention to this.

Common misconceptions with visual treatment, particularly color. A leading source of confusion and misconceptions arise from visual design and color choices used in the visualizations. This is particularly an issue when color schemes that are usually associated with a certain, common meaning are applied to other data and meanings. The Ozone visualization (see Figure 5.7) offers an example of how using a rainbow color scheme in a data visualization, which is often associated with thermal measures that present hotter temperatures as red and

Figure 5.2. Sea Ice Raw Visualization: Data Artifacts

Figure 5.2. Still Image from Sea Ice Raw Visualization showing circular artifact in data. Screenshot used with permission from the American Museum of Natural History.
colder as blue/purple, caused considerable confusion in the meaning that teachers derived from the visualization:

PD leader: What did you think this was? [Points to Ozone visualization (Fig. 5.7)]

Teacher 1: Seasons

Teacher 2: I thought it was temperature.

Teacher 3: I thought it was temperature too.

Teacher 2: But then that didn’t make any sense.

Teacher 1: It did look thermal in nature, because of those colors, but then during the winter it wasn’t that the color changed, but that greeny thing went away and you actually saw landforms. I wasn’t sure what that was about.

Figure 5.3. Global Ozone Raw Visualization: Color Display

Figure 5.3. Still Image from Ozone Visualization showing red coloring near the North Pole during winter. Screenshot used with permission from the American Museum of Natural History.
Resource and support needs (Res. Ques. 3D).

Throughout the study, teachers expressed a range of needs for further resources that would help them in their instruction. They were asked explicitly on multiple occasions throughout the study, verbally and in surveys, if they had any specific needs regarding the format of the visualizations or support materials that would help them with curricular integration. After teachers had used the visualization(s) in their classroom, they were also asked to reflect on what would have been useful for them in their instruction that they might not have anticipated. From these data sources, patterns of more frequent requests emerged that are described in the following sections.

Need for flexible visualization versions and formats. Teachers were provided each of the five visualizations in this study in multiple versions (raw and produced/annotated) and formats (DVD and online streaming), which offered a wide range of affordances for instruction. Teachers used the visualizations in an even-distribution of various combinations across the versions (i.e. produced, raw, or a combination of both). The following representative comments from three teachers provide further insights into the reasons that many teachers wanted multiple versions of the visualizations:

Teacher 1: I liked it because of the unfinished, or the raw, and then the finished one with the words. It was a good way to see what they were thinking when they when they saw it because normally we just show a video or a clip and it's talking to the kids and its telling them what's going on, but I like seeing the unfinished version, seeing what they thought, and then going from there, playing the completed version and seeing if their thoughts had changed.
Teacher 2: And I even like the format that these were in, the one where you could guess what it was and the other one with more information.

Teacher 3: I’ve realized for a long time that if I could find a really nice video clip, I don’t like to sit down and show lots of long video, but the one nice thing about the format of the videos that you showed us was that they’re short but they’re complete enough to present a good concept. Gosh, if you could have like fifty of those, spread out throughout the important topics in Earth and Space Science, that would be a good base for a curriculum I think; something to build a curriculum around.

The format that the visualizations were offered in was considered important in regards to the technological infrastructure that teachers had in their classroom (bandwidth and strength of their internet connection, their projector and laptop set-up), as well integration of the visualizations into the delivery mechanisms that some of them used for their instruction (i.e. Power Point Presentations). Almost all teachers reported using the DVD format to access and use the visualizations in their classroom instruction, as the following teacher comment reflects:

Teacher 1: We have problems sometimes with Internet access, so I try not to have anything requiring live Internet access during class, just because it breaks down, like yesterday it did. So, if I was using a movie or anything and counted on it, I wouldn’t have it. Having things like this in my hand (indicates the DVDs) is very important, not just a feed from NASA somewhere.

**Importance of audio.** The visualizations used in this study were initially developed for use in kiosks in informal science education settings, so no audio narration was provided. Many teachers, however, saw a need for the produced versions of the visualizations that had on-screen text to also include, or offer, an audio version of the narration, particularly to support diverse
learners. The following comments represent the range of teachers’ feedback on the matter of audio components:

Teacher 1: But I had one thing…for kids who aren’t good readers, they don’t read well, do they have auditory?
Teacher 2: That’s what I was wondering
Teacher 3: I would have sound on the completed version reading the script. Maybe if they’d go a little bit further or talk about the actual data that goes with that.
Teacher 4: You have to read to them because they can't read the screen, what's going on, so [the Global Clouds] one was a little tough for them. But I could point out, I could hit stop or pause and “okay, you see what's going on here? This says this is happening here. And you see this?” And I had to point things out to them, so it really needed a lot more instructional help from the person using it at the time…
Teacher 5: Well… it was okay, again. I think though for the lower level learners that maybe can't read, the special needs students, that a vocal to go along with it.

But not all sound was welcome in their instruction:

Teacher 1: In Global Cloud patterns, the music was annoying. Lose the music. It was awful. I had to mute it.

Need for standards alignment. Multiple teachers in the study expressed difficulty in integrating the visualizations into their classroom instruction because the topics and concepts that the visualizations addressed were not included in their curriculum. The following comments are
representative of the theme that emerged for the initial visualization offerings to be curated or
developed from the content needs of the content standards or teachers’ curricula:

Teacher 1: I think part of the problem…I think these are excellent. And I’ll use a lot of
this stuff. But the problem is we have state standards and we have to teach, and a lot of
this has nothing to do with our state standards. So, if you, as an educator, could somehow
go through state standards and coordinate the ones that apply to the state standards, that
would be tremendous.

Teacher 2: [The Earth’s Magnetic Field visualization] is the only one I got to use because
I didn't teach the other topics, didn't get a chance

**Need for instructional supports and information for teachers.**

Over the course of the experience, teachers expressed needs for a range of supports and
information, for both them and their students. These were particularly needed during curricular
integration efforts, and the following comments taken from teachers’ closing interview
transcripts are representative of the key types of resources they requested.

The need for targeted background information about the content of the visualization:

Teacher 1: I was looking for more background information. Time, time is the thing. To
go and find something, I can find a NASA site, but to find the one little tidbit of
knowledge *I'm* looking for, that goes with that one particular thing. That background
information, it just takes time…. I guess I want to be spoon fed. I just need the Cliff
Notes version that I can deliver to my students that they need to know about this, and
they can do more research or whatever. So that one sheet, along with this thing, was nice.
You had some questions on there, but you didn't have answers, and I'm not a student I'm a teacher, so I need the answers. That would be good.

Teacher 2: Maybe like the paragraph that explained it? If there was more information there, background information for like a novice teacher, kind of like I was this year, a teacher that doesn’t have a real strong science background…. More information that I could share with the kids because when I read that- it’s very interesting and the kids had a lot of questions and I couldn’t answer them.

In addition, the need for supports that could be used with directly with students:

Teacher 1: I probably would've given them a sheet with questions to think about beforehand and maybe talked a little bit about it. Had them thinking about it as the movie, visualization, was going on.

Teacher 2: Probably follow up activities for the students.

Teacher 3: If they had something packaged for you, just a little link on there, “Resources for Teachers” and it was just a little de-briefing kind of questionnaire, hand-out…. If you had a little 2- or 3-page thing for each one of [the students], I could maybe, over the course of the trimester, have them fill out all of them. Like a little journal, this time they might visit this one, and next time they might visit that one.

Multiple teachers mention wanting the kind of information that was included in the Package of Support Materials that they received with the DVD during the PD. When they were reminded that they had received these materials, they did not remember seeing them, and one had even lost the printed packet:

Patty: Student guides. If we had some kind of student guides.
Researcher: What would a student guide consist of?

Patty: Next steps, where to go next for them. Maybe just some questions. Maybe something like, “Now write about, answer this question,” to see if they really understood what the visualization was.

[Researcher points out the Guide that was provided with the DVD]

Patty: I don't remember a list of questions [she takes out the guide and looks through it] oh, there we go [she finds the questions in the packet]. See, I didn't see that.

Researcher: Is that the kind of thing that you're looking for?

Patty: Yeah that's the thing. I wouldn't have known, like, “bow shock.” I wouldn't have even known to ask that question. I would've had to look it up to see what it is that meant to give them the vocabulary that went along with that. Yeah. See not all of them have that.

PD program recommendations (Research Ques. 3 E).

In addition to feedback and needs surrounding the visualizations and materials, teachers also offered suggestions regarding both the content and the format of the PD program. Data sources for this included the PD program evaluation survey that teachers completed at the end of the PD program and the transcripts of the closing interviews, where they were specifically asked if they had any recommendations, now that they had used the materials in their instruction, that the PD program could have better prepared them for. The following themes emerged from teachers’ responses.

Importance of timing of the PD program. Multiple teachers said that the timing of the PD program in the fall, when the school year was well underway, made it difficult to integrate the visualizations into their current school year lesson plans.
Teacher 1: I got them in the school year and once the school year starts it's just like a snowball going down a hill, it really is it's hard to do lesson writing and curriculum writing during the school year, so over the summer is a wonderful time. The beginning of the summer would be a great time to get a hold of it, you know like the spring, something in the middle of summer... workshop would be great. To say, “Hey, come on in and let's get some materials you can start the next year off with!” So, you gonna have one of those?

Teacher 2: The only reason that I didn’t show the other ones that I received is because I just didn’t have time to look at them. And hopefully...I’ll get those out this summer and look at them and see where I can use them in the curriculum.

*Model instructional usage during PD program.* Many teachers implied, and a few teachers explicitly requested, the opportunity to practice or have others model instructional strategies for using these kinds of visualizations with their students. In the absence of direct teacher instruction, multiple teachers reflected on adopting the approach that was using in the PD program; presenting the raw version, using it to ask students what they thought it was they were seeing, and then presenting the produced version to discuss the meaning and concepts behind the representation. Two teachers provide examples of this feedback:

Teacher 1: This is my first-year teaching science, 8th grade science, and my personal background is very weak. I think I learned more than the students this year. This year what I did was, I used all of them pretty much the way you did when we were at the inservice [PD] thing. I played them for my students and then I let them guess at what was going on and then we played it again with the- one of them was like plain and the other one has information on it? So, I played the one that was just plain, and I let them guess
and try and figure out what it was, we watched some of those twice, kids were so excited about it and they liked the fact that they were “real.”

Teacher 2: When we went and looked at the visualizations…it would have been nice if maybe some of the things that you were wanting to have us do was done with us.

[Researcher probes for more specifics.]

Like almost instead of us being the research subject, …it would've been nice if we were almost treated like the pupil, and the person who was there was like the teacher….

And obviously you’d have to remember that we're not talking to 12-year olds, you’re talking to a 40-year-old women, and do it in that vein. But kind of get the sense of this is one way that you could really pull your kids in. Bring up the point that you know right where you are, is where your kids are. They don't want to be wrong either, so right now, what would ease your discomfort? What would make it easier for you to make a mistake right now? Put them in their kids’ shoes so that we can help them get over this hump.

**Include time for lesson planning.** In addition to modeling instructional strategies, multiple teachers requested that the PD program include more time to explore the visualizations and materials that they received, and an opportunity to workshop the integration of the visualizations into their specific lesson plans in a collaborative or supported way:

Teacher 1: I think that there're a lot of resources out there that we are kind of afraid to get into and we don't have to time to explore. I mean, almost half the [PD] time would be getting comfortable using it, rather then you just dive right in there.

Teacher 2: Part of that- you know as a teacher, going to the [professional] development, it was great to get those [visualizations], but it's great to have that focus too. “When you walk out of here today you're going to have a PowerPoint you can take back your class,”
that you've created for bringing one little lesson that you want to teach about one of these topics- send your little thing out here on sea ice- one thing you want to teach about this thing that you want to drop this into.

Time for lesson planning should also explicitly address methods for the technological integration of the visualization files into popular instructional delivery methods. For example, downloading and embedding the visualizations files into PPT was a popular way that teachers in the study integrates them into their instruction. However, not all of them understood, or were comfortable, with embedding and use the files this way. As a result, many resorted to playing them directly off the DVD:

Teacher 1: I would like them to be downloadable on my computer so I can put together a PowerPoint, that I could put it into the PowerPoint, and surround it with my other information. That's what I really want.

“Teach me to fish” The exposure of teachers to data visualizations such as these had the unanticipated impact of providing them with an awareness that led to a more targeted search strategy moving forward. As one teacher in the study shared when asked about additional visualizations that they mentioned finding and using in their instruction:

Teacher 1: I Googled it. But you gave me a word, you gave me “visualization,” so I would type up “plate tectonic visualization” and that would get me where I wanted to go quicker…. That's what I wanted, because if I just typed in “plate tectonics,” I get Wikipedia…. But, because I put it in individually it would get me the other places and there was this- I can't think of what it's called- but there is this one that has a ton of visualizations. So, you've taught me what this thing is and how much they can enhance learning because a lot of it you can't physically take them to.
I will conclude this section on teacher impacts with the voice of one teacher who shares her final thoughts on why visualizations such as these are value to her as a science teacher:

I think that it's neat because it’s stuff that wasn't available when we were students, and I think that's the hardest thing to do as a teacher cause you, a lot of times, teach how you were taught. So, we’ve got to make sure that we use those resources, and that they're available, and that we do need help doing it because we've never seen it done before.
Chapter 5
Discussion and Conclusion

Research Question 1

*What do science teachers bring to a data visualization experience that takes place in a professional development setting?*

**Content Knowledge in Earth and Space Science.** While the intent of the professional experience offered in this research study was not targeting to change teachers’ content expertise, it was important to understand the depth of content knowledge, as a dimension of TPCK, that teachers were operating with, particularly during their initial exposure to the science visualizations and during their instructional implementation.

The science teachers in the study had a wide range of background coursework in Earth and Physical sciences, as there was an almost even distribution of Low, Medium and High scores among the eleven teachers (see Table 4.1). They demonstrated the same broad variance of scores for their measured content knowledge in Earth and Space science topics; Low (N=3), Low/Medium (N=2), Medium (N=1), Medium/High (N=1), and High (N=4). Teachers’ level of background coursework corresponded closely with their content knowledge measures from the study (see Table 4.7). The greatest deviation among content knowledge cores came from the comparison between the Moon Formation Storyboard and Weather and Climate Concept Map due to some teachers having much greater expertise in domain-specific topics of Earth science than for Space science topics. Future instances of such research should constrain the visualizations to a single, focused, domain-specific content area if impacts on teachers’ content knowledge are an area of focus in the research study. To the best of my knowledge, there is very
little research in the literature that examines teachers’ content knowledge of the Earth and Space science topics addressed in this study.

**Teachers’ Understanding of Data Visualizations.** Research has identified three important distinctions in the conceptualization of visualizations; (1) as objects, such as pictures, computer-generated displays, simulations, videos, etc., (2) as mental objects pictured by the mind, and (3) as a cognitive action or interpretive device that involves making meaning from visualization objects in relation to one’s existing network of beliefs (Vavra et al., 2011). In general, teachers entered this study with an object-oriented conception of scientific visualizations, with seven of the eleven participants (64%) exclusively describing a scientific visualization as an object that was most frequently an external representation format (i.e. picture, video, diagram, etc.).

Five of the teachers (45%), four exclusively, held initial conceptions of science visualizations as interpretative (see Table 4.9), involving a cognitive process of interpretation or perception and meaning-making. It is important to note that three of the teachers with conceptions of visualizations as Introspective devices (“IP”) had a High content knowledge score, which hints that teachers with deeper understanding of the content are able to recognize these types of science visualizations as conceptual models of natural phenomena and systems, and less as media products and representations.

Teachers’ responses regarding the nature and source of the data used to make the raw visualizations in the study allowed for another way to probe their understanding of what scientific visualizations represent and how they are produced. Because two different types of data visualizations were used in this study, Earth systems visualizations that use remote sensing and satellite data (viz. 1, 3 & 5) and Space visualizations of computer simulations and models
(viz. 2 & 4), a clear distinction emerged between teachers’ understanding of the nature of these two types of visualizations.

The source of data for the Earth visualizations used in this study was most often understood, correctly, to be satellites, with a heavy role for computer enhancement and simulation (see Table 4.11) mentioned as part of their development. Things were less clear to teachers regarding the two space visualizations. Teachers most frequently believed that the origin of data for the Earth’s Magnetic Shield visualization (viz 2) was from satellites or spacecraft. However, the Formation of the Moon visualization (viz. 4) was correctly understood by many of the teachers to be based on a mathematical or theoretical model that was generated by a computer (simulation).

These differences can most likely be accounted for by the visual presence of the Earth in the Magnetic Field visualization, which many teachers pointed out during their Individual Interviews as soon as the Earth’s sphere became discernable within the blue veil of the magnetic field (around 0:13). Further, the cinematic flight path taken around this Earth system triggered a sense of realism that could have connected the visuals to the three Earth-based visualizations in this study, which were most frequently viewed as originating from satellite data. Additionally, while the phenomena in the Earth’s Magnetic Shield visualization was not associated by teachers with any specific time period, it could be contemporary, and therefore derived from recent satellite or spacecraft observations. In contrast, teachers understood that there was no opportunity for direct observation of the formation of a planetary body, particularly of the Moon and early Earth, and therefore they understood it to be based on a theoretical or computational model.

As scientific visualizations become increasingly realistic-looking due to advances in computer-generated imagery (CGI) and special effects, it becomes critical for teachers who are
seeking to instruct with these types of data-driven science visualizations to understand the nature and source of the data used to generate them, and what they do, and do not, represent.

**Instructional Use of Visualizations.** When initially asked about their use of scientific visualizations in the pre-survey, teachers reported a much higher instance of usage than when they were actually shown the five dynamic data visualizations in this study and asked if they used *these types* of visualizations in their instruction. This distinction shows that teachers see little distinction between the term science visualization and other media formats and representations that are included in instructional materials.

Once exposed to the data visualizations in this study, few teachers reported using similar visualizations in their instruction. The majority of reported instructional usage came from the use of weather maps that teachers got from the Internet (i.e. NOAA and NASA sites), or from the Weather Channel, and were responses associated with the Global Clouds visualization (viz. 1). Teachers’ reported only a few prior instances of usage for visualizations similar to the remaining four visualizations in the study, with the sources being videos and films that included these simulations within the context of a narrative story or program (i.e. *The Day After Tomorrow*, and NOVA or Discovery Channel programs). One visualization, Global Ozone (viz. 5), had no prior usage of a similar visualization associated with it.

What is interesting to note is that the sources for visualizations that teachers report for their instruction are almost entirely instructional resources that are included in instructional products and educational distributors. Besides one reported Internet source for Earth maps that explicitly notes NOAA and NASA, there are no further sources of science visualizations reported that are primarily scientific organizations that offer data and visualization products. As scientific
agencies and researchers increasingly make their data products available, it will be important to track this pipeline from “science products to classroom.”

**Research Question 2**

*When supplied with a set of data visualizations, how do teachers integrate and implement them into their domain-specific instruction?*

**Case Study 1: Patty.** From her very first question in the PD program, Patty sought to understand the type of visualizations in this study to be, “in its most simplistic form, is it just a model?” She was one of the only teachers who frequently, and adeptly, shifted to “addressing her students” during her Individual Visualization Interview and the PD program, as she practiced the questions that she might ask her students if she were teaching with these visualizations. While Patty had one of the Lowest levels of content expertise, and was in her first year of teaching science, she could be seen as the expert teacher in the group in using an inquiry approach with her students. It was notable that she wrote, “A Love Story,” on her Moon Formation Storyboard, and throughout the PD program she shared many examples of real-world stories that she associated the visualizations with, such as “Kilimanjaro’s snow melt,” “Polar bears,” and, “seeing the Northern lights.” Patty also considered herself a learner, and she expressed that she drew on her own experience of personal struggle during the initial visualization exposures to understand what her students would face when introduced and asked to make meaning from the visualizations. In her closing interview she discussed how she asked targeted questions of her students to make sure they were noticing, and understanding, certain visual features that were critical to the deeper understanding of the model and system in the visualization (i.e. the spiraling motion of the solar wind during interaction, the location and colors of the aurora, etc.).

It is important to recognize that the curricular needs and learning goals that Patty had for her students, the structure and function of the Earth’s magnetic field, allowed her to have a
deeper integration of this visualization into her lesson than many of the other teachers observed in this study. At the end of the study Patty valued these types of visualizations because they provided her with representations that offered her students access to phenomena than her students had previously had difficulty experiencing visually, or at all, in the classroom. Her measure of value came from the questions and ideas that she was able to generate from her students.

In conclusion, Patty’s approach to using the visualization with her students generally included developing a shared understanding of the computational model represented in the visualization. Patty’s approach used a teaching sequence with her students that (1) asked students to articulate what they were seeing in the representation and guiding them in connecting concepts and ideas that emerged with familiar meanings and representations previously encountered in their instruction, (2) sought to develop a shared language about the phenomena (i.e. fields, poles, etc.), and (3) explicitly noted where there were limitations to the visuals and data that could be confusing or misunderstood.

**Case Study 2: Bob.** While Bob had a higher level of content knowledge than Patty, his instructional approach could be said to include very limited opportunities for student inquiry. Data from this study reflects a pedagogical approach that places value on the transmission of knowledge from teacher to student, as evidenced in the “cookbook” style lab activities he reports in his pre-survey and his many, repeated uses of the words, “tell them” and “show them” throughout his Individual Interview and PD transcripts. Bob sees these visualizations as an incremental improvement on video-based representations that he has used in the past, although more interesting and engaging for introducing topics to students due to their dynamic nature and production style. While Bob does use both versions of the visualization, first the raw version and
then the produced one, his instructional approach of showing them the raw version, asking them what they see, and then showing them the produced version to see if “they got it right,” does not utilize the raw visualizations to elicit student ideas of the conceptual model represented in the visualization. Rather, the questions that he uses to frame the raw visualization are focused on having students provide a complete, final answer that reflects his learning goal for the lesson (“and that is how the Moon was formed”). This implementation is almost like using the raw visualization as a visual version of a fill-in-the-blank worksheet. This instructional implementation is consistent with using the science visualizations as an “object”, specifically, as a multimedia video that communicates an already-set idea or content narrative.

Regarding Bob’s curricular integration of the visualizations that he used, it is important to note that he did express that his curricula was already established and that the visualizations provided in the study were not strongly-aligned with the lesson plans and learning goals that he was required to teach. While this shallow content alignment impacted the depth of curricular integration that was possible for Bob, using the Moon Formation visualizations at the beginning of a Phases of the Moon unit, the instructional strategies that he used in this observed implementation were consistent with other instances that reflect an overall non-inquiry approach in Bob’s instructional approach.

**Through the Lenses of TPCK.** In this section we examine the data from the two case studies, with a particular focus on the classroom observations, to analyze the knowledge and skills that Patty and Bob utilized when teaching with data visualizations.

**Content Knowledge.** While Bob’s content knowledge in science was stronger than Patty’s, “for teachers, content knowledge includes not only their subject area knowledge, but their understanding of the applicable curriculum standards. (Hofer & Swan, 2006)” This project
asked teachers to connect and integrate one or more visualizations into their curriculum. While none of the five visualizations were explicitly designed to address educational standards, they all presented phenomena that could be connected to the core ideas of the standards. It was in this way that Patty’s content knowledge proved more effective. She connected the Earth’s magnetic field to her lesson about the inner structure of the Earth’s core and its generation of a magnetic field to enable students to make observations around its structure and the role it plays in protecting the Earth’s atmosphere. Bob more superficially connected the Moon formation visualization to his unit on the phases of the Moon. This loose content connection led to student discussion that was of little value to Bob in advancing the learning goals that he had for his lesson, causing him, and his students, to quickly move on.

**Pedagogical Knowledge.** The most striking difference between Patty and Bob was the difference in their instructional approaches. Patty conformably employed a student-centered approach to orienting students to the visualization and supporting them in making observations and connections. She was skilled in facilitating discussion among students that would probe their reasoning in fruitful directions for her learning goals. Her expertise in this approach is also evidenced in comments that she makes in both the PD session and her closing interview about how her goals is to elicit students’ ideas and questions, to provide, “the fodder for discussion.” In contrast, Bob employed a teacher-directed approach in his instruction, keeping to a tight schedule to get through the topics that he needs to cover that day/lesson. On those few occasions that the lesson started to generate student discussion, such as students sharing that they saw the Moon in the sky, Bob would quickly step in to quiet everyone down and get back “on task.” This approach offered minimal opportunities for active engagement with the visualization.
Technological Knowledge. Both Patty and Bob were on even footing regarding their technological knowledge and experience, particularly around using videos and media in their classroom. However, there was one aspect of visualization usage that was not directly observed in the classroom but was mentioned in the closing interviews. During their observed lesson, both teachers played the visualization that they had selected for the entire class. However, Patty described another way that she uses technology that is responsive to the needs of her students and lesson:

Some times when I'm teaching and I get that “cricket moment” when they're just not getting it, they don't see it, they don't understand it, and it's like, “oh, if you could just see this,” what I'm talking about, you know maybe it would bring it closer to your understanding. So those moments, and there're times when I'm like I'll stop and I'll go to the Internet and I'll try to search for one real quick to see if I can get one.

From her participation in this study, Patty shared that she now had another word to add to her search term. “But you gave me a word, you gave me visualization, so I would type up ‘plate tectonic visualization’ and that would get me where I wanted to go quicker.” It is important to note here that Patty frequently streams the video content that she shows in her classroom from the Internet, while Bob used the DVD for playback, which was still an important part of most classroom media technologies. With online streaming now often the only option for classroom use of media, the use of “live and responsive” internet searches that Patty during the course of classroom instruction that Patty exemplifies could only increase.

Pedagogical Content Knowledge. Once the teachers decided what topics they were going to address with the visualizations, then needed to determine how they were going to facilitate learning with of content. The vision of the Framework (2012) is student engagement in science
practices to learn core ideas and content. Therefore, active student engagement becomes evidence when looking through this lens. Patty asked her to students to make observations from the visualization, communicating what they saw and using their observations to make inferences about the underlying Earth system or feature. She paused, and pointed, to break up the experience into a level that her students could handle, and sometimes gave them control of the screen to walk up and take a closer look. Her implementation was a powerful demonstration of guided inquiry that resulted in a high degree of student engagement. Bob’s classroom implementation was more directed and didactic, with quiet and passive student watching of the video. He did ask students what they saw in the visualization, but a successful answer was connected to vocabulary recall. Student discussion was not valued or included in the instructional implementation. Student engagement levels were low, and not one student asked a question at the end of the viewing when Bob asked, “Any questions?”

Technological Content Knowledge: In the context of this project, this dimension of TPCK is operationalized in the knowledge and instruction of the nature of the visualizations themselves; how they are made, their relationship to scientific research, and their use as a representative model of an Earth or Space system. Neither Bob nor Patty explicitly framed or discussed the nature of the data visualizations and how they were watching a video of a scientific model that was used to run a simulation in a computer.

Technological Pedagogical Knowledge. Technology and pedagogical knowledge intersect in how the teachers frame and orient students to the media, so that they are prepared to make meaning from it. Patty used two techniques to scaffold students in making observations. First, she tells them what they are going to be watching and goes beyond the topics/content. They she gives them a guiding question. “We are going to watch this with no sound. What do you
see?” The second technique is that Patty shows it multiple times, pausing during the second viewing so they have time to make their observations and discuss. Bob provides no guidance on what to look for in introducing and framing the visualizations, saying only, “Now I am going to play another video, I am going the be reading the text to you.” He does not compare the two and point out different features in the representations. In this way, he limits the effectiveness of the video for student learning.

**Looking Across the Case Studies.** What is striking about comparing these two cases holistically through the intersection of all TPCK domains is the symmetry of key aspects of their instructional implementations juxtaposed against the very different instructional strategies that they used with their students to frame and support their viewing. These differences resulted in dramatically different levels of student engagement and teacher-perceived learning outcomes. Both teachers used the visualizations at the start of a unit to offer introductory engagement with a Space concept. Both teachers showed the raw version of the visualization and asked their students what they saw, replayed it a second time and stopped at certain points during the second viewing. But while Patty continually asked her students about what they were seeing (“they need to be able to be wrong, and to be okay with being wrong.”), and probed for deeper meanings behind the visuals, Bob was looking for students’ answers to confirm that they were getting the information from it that he was trying to convey to them by comparing answers against the background information about the visualizations.

While both teachers asked students what they saw in the visuals, Patty used student responses as starting points to probe their underlying conceptualization of the model (i.e. referent) behind the visuals (“What do you think that means? Tell me more.”). With his questions, Bob was seeking students to provide facts and information that he took as evidence
that they had met the learning goals that he had for the lesson, which were accepted as correct when in the form of fact-based statements and the correct vocabulary terms.

The essential difference between these two instructional approaches are that Bob had a set learning goal that he was seeking to teach his students, and he used the visualization as an engaging, dynamic representation to communicate the targeted information, while Patty used it as a way to probe her students’ understanding (i.e. as a formative assessment) by offering it as a shared experience with a phenomenon, like a field trip to the Earth’s magnetic field.

Research Question 3

How were teachers impacted from the visualization experience?

Teachers’ Change in Content Knowledge (Research Ques. 3 A). Changing teachers’ content knowledge in Earth and Space Science was not a goal for this professional experience and content-specific discussions during the PD program were limited to deepening teachers’ understanding of the referent systems and models in the visualizations. The pre-post scores of teachers’ content knowledge reflected this, with an average increase of only 0.6 points (from 6.2 to 6.8) in teachers’ content knowledge scores. It is important to note that post-assessments of teachers’ content knowledge did not include examining changes in their Moon Storyboard or Weather Concept Maps artifacts, which would have been more likely to reflect any impact on teachers’ mental models since these topics/systems were included in the visualization explorations portion of the PD program. Future research along these lines should seek to include pre- and post-measures of teachers’ mental models for concepts represented in any visualization(s) used, using the concept mapping instrument used in this study, and it is recommended that a single, domain-specific topic area, for example Earth or Space science, be the entire focus of any one PD program workshop.
Change in visualization understanding (Research Ques. 3 B). Five of the eleven teachers (45%) changed their views of what science visualizations are over the course of this study (see Table 4.20), and those changes were towards conception of visualizations as “objects.” At the end of the study, all but one of the teachers’ held understandings of visualizations that were either solely, or included, them as objects. And for those few teachers who still maintained an aspect of their understanding of visualizations as interpretative devices, the descriptors that they used (see Table 4.21) demonstrated a slight shift from a more cognitive understanding (i.e. mental image) to a more perceptual meaning (i.e. view, show, presented).

Looking at the descriptors teachers used for the object-specific responses, Table 4.22 offers insights into the reasons for this shift towards a stronger view of visualizations as objects from this professional experience. Frequent use of the terms, “visual representation,” “type of video,” and “display,” mirror the language used in the PD program. This was an unintended consequence of needing to focus on supporting teachers in the technological integration and delivery aspects of their classroom usage. These conversations about how to present the visualizations placed an emphasis on the available formats and how the video files could be accessed from the DVDs or Internet and embedded into classroom technologies (i.e. Power Point, projectors, etc.) for presentation to/with students.

While specific teachers voiced questions about the visualizations being used and understood to be models, and the PD leader/research reinforced this conception, it is clear that a more direct, up-front framing of these types of representations as conceptual models of natural systems and phenomena should be core to future professional development efforts.

Teachers’ Questions about Visualizations. The overall pattern of question types and frequency that teachers asked about the visualizations from their initial exposure and through the
PD program aligned with the general arc of experience as a learner/viewer (1) initially perceives the representation, (2) seeks to make meaning by connecting it to prior knowledge and existing conceptual/mental models, and finally (3) extracting from it some deeper meaning or information about the underlying concept, phenomena or process that it refers to.

The most frequent type of question asked were “display” questions, as every teacher started with the first step of initially perceiving the visuals displayed when first presented with a visualization. Many teachers, particularly those with lower levels of content knowledge, never made it beyond this initial step, and their display questions sometimes never went beyond a general question of, “What is it?”

Those teachers that moved beyond the initial display features began to make meaning of the visuals and connect them to the underlying referent model or phenomena. This was when teachers sought validation that their assignments were accurate (“are these ocean or wind currents?) and began to probe the limitations of the data included/represented in the visualization. This was also when data artifacts (i.e. representing gaps in the data set or observations) and color choices can most impact the understanding that the learner derives from the visualization.

Finally, this research study demonstrates the value that teacher questions can play in understanding where teacher/learners are in their consideration and understanding of these types of visualizations. If teachers in a PD program have not moved beyond questions of the visual features and initial meaning making and into an exploration of the deeper conceptual system that it refers to, then additional time and support should be spent on this aspect of the visualization(s).

**Resource and Support Needs.** Most of the literature has studied visualizations that have already been integrated into curricular materials or computer-based learning environments that
already include scaffolding and guidance directly to students. This research instead starts with

data visualizations in multiple forms of raw and produced narratives, that are provided in the

format of short videos (approximately 3 to 5 minutes). This study then seeks to understand how
teachers use these more flexible forms, and what they need to support their particular
instructional usage. This approach led to a diverse mix of curricular integrations approaches that,
with only eleven teachers in the study, resulted in every possible permutation of usage (raw-only,
raw + produced, produced only, etc.). It was clear that having the “raw” versions were valuable
to the teachers, with many teachers independently dubbing them the “inquiry” version.

Teachers in this study specifically requested (1) visualizations of concepts that provided a
strong alignment to educational standards, (2) questions and vocabulary to use directly with their
students, (3) accompanying activities and recommendations for curricular integration, and (4)
detailed information about the content and data that is included/represented in the visualization.

**PD Program Recommendations.** Many teachers expressed an interest and desire to
continue to use science visualizations like the ones in this study for their instruction, but they
recognized that professional development was crucial for their success. Multiple teachers asked
in their closing interviews if, and when, the next workshops would be offered. One teacher even
expressed that learning the term, “data visualization” had helped her better search and target
these kinds of videos for other topics in her curriculum.

Those few teachers who understood/approached these data visualizations as a model of a
system or process, and used it as such in their instruction, found it to be a powerful tool for
formative assessment and student engagement, among other instructional uses. The results of this
approach were sometimes overwhelming in their success. As one teacher reported, “I was
shocked,” what I was hearing [regarding her students’ ideas]. “I couldn’t believe the questions
they had.” It is important to consider not just teachers’ instructional practices when bringing these kinds of visualizations in the classroom, but to also prepare teachers for the increased level of student engagement and responses that they can expect when instructing with them, so teachers are not, as one in the study said, “scared-off.” The emerging field of Modelling-Based Teaching (MBT) holds much potential for providing strategies and approaches to teaching with the types of dynamic visualizations in this study (Gilbert & Justi, 2016).

A few general considerations emerging from this study have implications for the design of future professional programs that seek to support teachers in instructional implementation of these types of visualizations. They include: (1) provide time and content support for teachers to explore and develop a deep understanding of the data and concepts that the visualization(s) represent, (2) explicitly address, and provide teachers with time to practice and model with each other and with PD leaders, instructional strategies for engaging students actively with these types of visualizations, and (3) include time for curricular integration and planning, with particular supports for technological integration for classroom delivery.

Conclusions and Implications

If the exponentially increasing volume of data products that is emerging from computational science is going to be fully realized for instructional use in the vision of the Framework for K-12 Science Education (NRC, 2012), then educational researchers and instructional designers need to better understand the experience and needs of the teachers as they seek to understand, integrate, and instruct with them in curricular and classroom contexts. The arc of this experience, through the varied lens of TPCK, is what this study sought to better understand. Some key areas for future research emerged that are addressed here.
Teachers see value in dynamic data visualizations. The potential for student impact and engagement was central to the interest, and excitement, that teachers had for the type of dynamic, data-drive science visualizations used in this study. Authenticity was seen as a feature of the raw visualizations, with teachers noting the importance of connecting these in their classroom to “real science” and seeing “what the scientists see,” which could hold the potential for increased student interest and motivation. Additionally, multiple teachers mentioned the desire to connect the exposure and usage of data visualizations like these to scientific careers and more generally to data literacy skills that are increasingly seen as critical to college and career readiness in science (NRC, 2012).

Data Visualizations and Modeling. However, while visualizations and representations are not new to science instruction, computational models and simulations, in partnership with modern graphics tools, are infusing a new kind of data-driven visualization into science instruction. While teachers have used animations and instructional videos for decades in the classroom to better communicate or “show” phenomena not easily accessible to students. The types of data visualizations used in this study represent digital models that offer windows into systems and scales that haven’t previously been understood or explored in a data-driven way (simulation). Research shows that many pre-service and in-service teachers lack knowledge of models and modeling (Crawford & Cullin, 2004; Coll & Lajium, 2011), possibly due to limited understanding of scientific epistemology, or in learning the language of modeling (Ke et al., 2005; Tsai & Liu, 2005). Many of the teachers in this study never engaged their students with these visualizations in ways that had them use them as models—to describe, explain, or predict. It is important to note that the most successful classroom implementation observed in this study was the teacher, Patty, who asked the question at the very beginning of her PD session, “So in its
most simplistic form, is it just a model?” Moving forward, situating these types of data visualizations as digital models and developing pedagogical approaches that are grounded in model-based learning and instruction (Clement & Rea-Ramirez, 2008) but specifically for media-based implementations, will be key to successful instruction and learning outcomes.

**Active student engagement is the goal.** Learning disciplinary core ideas is not the only goal for using dynamic, data-driven science visualizations in instruction. Visualization design and teacher instructional practices should be synergistic in enabling/supporting students to actively engage in one, or more, scientific practices included in the *Next Generation Science Standards* (NGSS Lead States, 2013) for a targeted learning outcome.

**Potential to support learning with targeted populations of students.** While students as subjects were not in the scope of this research study, it emerged from many of the teacher interviews that they felt that certain student populations stood to gain even more from the instructional usage of these types of visualizations. These include multiple references to, “visual learners” and those students who are more primed and responsive to visual and media-based representations. One particular population of students that multiple teachers mentioned were English Learners and struggling readers. In this case, visualizations were seen as offering access to the phenomena with little to no dependency on vocabulary or reading, and in a manner that welcomed their own words and descriptions. Another population of students mentioned by teachers were those with a greater need for stimuli to be drawn into the lesson, who teachers called the, “video game learners.” In this case, visualizations were seen as offering dynamic and engaging representations that would “hold their attention” so that the teacher would interest them and motivate them to want to further engage in, and learn, the topic.
The science research to science classroom pipeline. The pipeline that starts with the data products of scientific research and leads to the K-12 science classroom is evolving and poorly understood. Currently, media assets and videos that were originally designed for communication, journalistic, and even marketing purposes are often leveraged for classroom usage in ways that are not strongly aligned with educational standards and learning goals. For computational science to have a sound and effective channel into classrooms through mechanisms that enable instructional experiences aligned with the vision of the Framework (2012), flexible user- and learner-centered instructional design approaches need to be developed and sustained teacher professional communities need to be developed and supported. Finally, producers who select, adapt and design science visualizations for instruction need to adopt cohesive visual approaches, especially within domain-specific areas, to better realize student learning across multiple visualizations (Ainsworth, 2006).

Towards a “Teachers’ Toolkit.” Scientific data visualizations have left the lab to become increasingly ubiquitous tools for communicating and educating audiences of all ages in a range of contexts. But just offering teachers access to science visualizations does not guarantee, or even enable, effective learning. Research on technology and learning has “concluded that [technology] has great potential to enhance student achievement and teacher learning, but only if it is used appropriately. (National Research Council, 2000, p. 206)” Likewise, “it has been clear for some time that any approach to instruction that ignores cognitive processes is likely to be deficient” (Chandler, 2004, p. 354). Rather than any one-size-fits-all curricular approach, the type of educative curricular materials that are needed to support teachers’ in using scientific data visualizations in their instruction is more aligned with a “teacher toolkit” approach that wraps visualizations with the background information, recommended adaptations, and supports
necessary to be used with diverse learners for a range of curricular integration approaches.

Moving forward, instructional designers should work with teachers in diverse classroom contexts to design this toolkit, and with educational media distributors to optimize mechanisms that bring scientific data visualizations into classrooms where they can become valuable, and accessible, phenomena for science learning. The nature of how we understand and access our universe is changing due to these data visualization technologies and methods, and it holds great potential for offering new ways to teach and learn science.
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## Appendix A

PD Program Agenda and Schedule

<table>
<thead>
<tr>
<th>Activity</th>
<th>Tasks</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
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<td>1 Introduction</td>
<td>Study Consent and Overview</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Agenda for PD</td>
<td></td>
</tr>
<tr>
<td>2 Content Exploration</td>
<td>Moon Formation Storyboarding</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Weather &amp; Climate Concept Mapping</td>
<td></td>
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<tr>
<td>3 Raw Visualization Exposure</td>
<td>Individual Interviews</td>
<td>30</td>
</tr>
<tr>
<td>4 Group Discussion</td>
<td>Understanding the Visualizations</td>
<td></td>
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<td></td>
<td>Watch and Critique Produced Versions</td>
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<tr>
<td></td>
<td>Distribute Educational Viz Package</td>
<td></td>
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<tr>
<td></td>
<td>Instructional Planning</td>
<td>90</td>
</tr>
<tr>
<td>5 Closing</td>
<td>PD Evaluation Survey</td>
<td>10</td>
</tr>
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<td></td>
<td>Next Steps in the Study</td>
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</tbody>
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Appendix B

Pre- and Post-Survey Instrument

Pre-Survey Items and Numbering
A. Demographics: (only administered in pre-survey)
1.1. First name:  
Open-Ended Response

1.2. Your sex  
Female  
Male

1.3. Year of birth:  
Open-Ended Response

1.4. Are you currently an in-service or pre-service teacher?  
in-service teacher  
pre-service teacher

1.5. If an in-service teacher, how many years have you been a teacher (including this one now ending)?  
Open-Ended Response

1.6. Check grade level(s) you are currently teaching (or will be teaching if pre-service):  
K - 4  
5  
6  
7  
8  
9  
10  
11  
12  
Undergraduate  
Informal Setting  
Other (please specify)

1.7. Enter the number of undergraduate and graduate Earth Science courses you have taken.  
Open-Ended Response

1.8. Enter the number of undergraduate and graduate Life Science courses you have taken.  
Open-Ended Response

1.9. Enter the number of undergraduate and graduate Physical Science courses you have taken.  
Open-Ended Response
1.10. Grade level(s) of Teaching Certificate: Check current (or future if pre-service) teaching certificate grade level(s). Mark one or more that best describes your situation:

- K-4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12
- Undergraduate
- Other (please specify)

1.11. Content area(s) of teaching certificate:
Mark one or more that best describes your situation. Please mark "not science" if your certificate is a general education certificate that covers all subjects but doesn't specifically include a separate science certification (e.g. as many elementary certificates do). Do not mark the "not science" category if your certificate includes content areas in addition to science. Please choose the correct area from the list or describe your content area in the "other science" category.

- Not science
- General science
- Biology/life science
- Chemistry
- Physics
- Physical science
- Earth science
- Astronomy
- Geology
- Other Science (please specify)

1.12. How would you describe the setting of the school that you currently teach at?
- Rural
- Suburban
- Urban
- Other (please specify)

1.13. Do you currently teach in a Title 1 school?
- Yes
- No

- If yes, which district?
- Open-Ended Response
B. Technology:
1.14. Please rate how important access to the following technologies are to you for use in your classroom instruction? (Select N/A if you do not have access to an item)

Not Important
Somewhat Important
Important
Very Important
Crucial
N/A (Don’t have)

a. Printer  
b. Projector connected to a computer  
c. Smart board  
d. Computer lab with at least 10 computers  
e. Digital Camera  
f. DVD player  
g. VCR  
h. Video camera  
i. Wireless Internet in classroom

1.15. Which of the following Internet technologies have you PERSONALLY used in the past year? (Please check all that apply)

Built a web page yourself  
Chat/Online discussion  
Created a blog  
Watched or listened to a video podcast  
Watched streaming video or webcast  
Listened to streaming audio (Real audio, etc.)  
Watched or listened to a podcast  
Video conferencing over the Internet  
Used Skype  
Used Facebook  
Used Twitter  
Other (please specify)

1.16. Which of the following Internet technologies have you used in your INSTRUCTION in the past year? (Please check all that apply)

Built a web page yourself  
Chat/Online discussion  
Created a blog  
Watched or listened to a video podcast  
Watched streaming video or webcast
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Listened to streaming audio (Real audio, etc.)
Watched or listened to a podcast
Video conferencing over the Internet
Used Skype
Used Facebook
Used Twitter
Other (please specify)

1.17. How frequently do you access the Internet in the context of your classroom instruction?

   Daily
   Weekly
   Monthly
   Less than once a month
   Rarely
   Never

1.18. When you use the Internet in your instructional PLANNING, what kind(s) of information or resources are you looking for?
   Open-Ended Response

1.19. When you use the Internet in your CLASSROOM INSTRUCTION, what online resources do you utilize?
   Open-Ended Response

C. Visualizations:

1.20. What is a “scientific visualization”?  Open-Ended Response
1.21. Can you give at least one example of a scientific visualization?  Open-Ended Response
1.22. Is there a difference between a “visualization” and an “animation”? If yes, how are they different?  Open-Ended Response
1.23. Is there a difference between a “visualization” and a “simulation”? If yes, how are they different?  Open-Ended Response
1.24. How frequently do you use scientific visualizations (as you have defined them above in #1) in your classroom instruction?
   Daily
   Weekly
   Monthly
1.25. Did you ever wish that there were good visualizations of particular topics or concepts that were available for your instructional usage, but you have never found one? What topics or concepts would you like to have good visualizations of to teach with?
Open-Ended Response

D. Content Knowledge:

1.26. What would best describe the short-term condition of the atmosphere?
- climate
- weather
- temperature
- humidity

1.27. Which type of clouds would most likely lead you to predict a thunderstorm?
- Cumulonimbus
- Stratus
- Cirrus
- Cumulus

1.28. The ozone layer of the atmosphere serves as a shield absorbing most of the heat from the sun, protecting against global-warming.
- infrared radiation from the sun, causing global-warming.
- ultraviolet radiation from the sun, protecting against skin cancer.
- cosmic rays, protecting against interference with radio transmissions.

1.29. What causes the weather?
Open-Ended Response

1.30. What can weather maps tell you about the weather?
Open-Ended Response

1.31. What is the difference between weather and climate?
Open-Ended Response

1.32. What factors determine the climate?
Open-Ended Response

1.33. As seen from your current location, when will an upright flagpole cast no shadow because the Sun is directly above the flagpole?
- Every day at noon.
- Only on the first day of summer.
- Only on the first day of winter.
On both the first days of spring and fall.
Never from your current location.

1.34. Imagine that the Earth’s orbit were changed to be a perfect circle about the Sun so that the
distance to the Sun never changed. How would this affect the seasons?
   We would no longer experience a difference between the seasons.
   We would still experience seasons, but the difference would be much LESS noticeable.
   We would still experience seasons, but the difference would be much MORE noticeable.
   We would continue to experience seasons in the same way we do now.

1.35. Global warming is thought to be caused by the
destruction of the ozone layer.
   trapping of heat by nitrogen.
   addition of carbon dioxide.

1.36. In general, how confident are you that your answers to this page of the survey are correct?
   Not at all confident (just guessing)
   Not very confident
   Not sure
   Confident
   Very confident

~

E. Pedagogy: (only administered in pre-survey)

1.37. Your students claim that winter is colder than summer because the Earth is farther from the
Sun in the winter.  (a) Please describe the currently accepted scientific explanation of the
phenomenon that the students are not understanding. (See directions at beginning of page for
more detailed directions.)  (b) Explain how you would address this misconception using best
instructional practices.  (See directions at beginning of the page for more detailed directions.)
Open-Ended Response

1.38. Your students explain that as a result of ozone depletion, ultraviolet radiation enters the
atmosphere from the ozone holes and reaches the earth. Ultraviolet rays are subsequently
reflected by the surface of the earth and trapped by the ozone layer, which acts as a glass around
the earth: it stops ultraviolet radiation, thus keeping it near the ground. This mechanism, known
as “the greenhouse effect,” is expected to cause the Earth’s temperature to rise.  (a) Please
describe the currently accepted scientific explanation of the phenomenon that the students are not
understanding. (See directions at beginning of page for more detailed directions.)  (b) Explain
how you would address this misconception using best instructional practices. (See directions at
beginning of the page for more detailed directions.)
Open-Ended Response

END OF SURVEY
Post-Survey Items and Numbering (sub-set of pre-survey items)

A. Technology:
11.1 Please rate how important access to the following technologies are to you for use in your classroom instruction?

11.2 Which of the following Internet technologies have you used in your INSTRUCTION in the past year?

11.3 How frequently do you access the Internet in the context of your classroom instruction?

11.4 When you use the Internet in your instructional PLANNING, what kind(s) of information or resources are you looking for?

11.5 When you use the Internet in your CLASSROOM INSTRUCTION, what online resources do you utilize?

B. Visualizations:

11.6 What is a “scientific visualization”? Open-Ended Response

11.7 Can you give at least one example of a scientific visualization? Open-Ended Response

11.8 Is there a difference between a “visualization” and an “animation”? If yes, how are they different? Open-Ended Response

11.9 Is there a difference between a “visualization” and a “simulation”? If yes, how are they different? Open-Ended Response

11.10 How frequently do you use scientific visualizations (as you have defined them above in #1) in your classroom instruction?

11.11 Did you ever wish that there were good visualizations of particular topics or concepts that were available for your instructional usage, but you have never found one? What topics or concepts would you like to have good visualizations of to teach with? Open-Ended Response

~
C. Content Knowledge:

11.12. What would best describe the short-term condition of the atmosphere?

11.13 Which type of clouds would most likely lead you to predict a thunderstorm?

11.14 The ozone layer of the atmosphere serves as a shield absorbing most of the

11.15 What causes the weather?

11.16 What can weather maps tell you about the weather?

11.17 What is the difference between weather and climate?

11.18 What factors determine the climate?

11.19 As seen from your current location, when will an upright flagpole cast no shadow because the Sun is directly above the flagpole?

11.20 Imagine that the Earth's orbit were changed to be a perfect circle about the Sun so that the distance to the Sun never changed. How would this affect the seasons?

11.21 Global warming is thought to be caused by the

11.22. In general, how confident are you that your answers to this page of the survey are correct?

~
Appendix C

Individual Visualization Interview Protocol

**General Introduction (Italics denotes what you say to the interviewee)**

Once you get settled and introduce yourself to the teacher, say the following to them:

[all side notes to interviewer are in brackets]

“We are going to watch a series of five short visualizations and you will be asked to answer the following questions about each one of them:

- What do you think this is a visualization of?
- Where do you think the data to make this visualization came from? (For example; satellite, computer simulation, etc.)
- What questions do you have about this visualization, or what would you like to know about it?
- How much time do you think is represented in this visualization? (Hours, day, weeks, years, etc.)
- What topics or concepts would you use this visualization to teach about, if anything?
- Have you ever used something like this before in your teaching? If so, what was it and where did you get it from (internet, DVD, etc.)?

You will then be asked to watch it a second time and “talk through” the visualization. This means that you should point to the screen and describe what you are seeing and what you think it represents. Imagine that you are pointing to it on a large screen in your classroom and describing it to your students or the interviewer, if that helps you.”

[To the interviewer: At this point, confirm that Garage Band is recording correctly on the laptop. If it is not, hit the round red button to start recording. Then hide the program so you will not have to see it. Allow it to continue recording throughout the interview.]

**Interview session (x5)**

“If you have no questions about this, then let’s begin with the first visualization”

1. Say out loud, “We are watching Viz 1” for the audio recording. Hit play and show Viz 1. Let them watch it quietly once. When it is complete, ask interviewee the following questions:

1-What do you think this is a visualization of?

[Pause for answer, probe further if they are not clearly explaining a concept by saying, “Can you tell me more about that?”]

2-Where do you think the data to make this visualization come from? (For example; satellite, computer simulation, etc.)
3- What questions do you have about this visualization, or what would you like to know about it?

[Repeat “Anything more?” prompt until subject indicates they have no further questions]

2. Say out loud,

4-We are going to watch it a second time. This time, we would like you to “talk through” the visualization. This means that you should point to the screen and describe what you are seeing and what you think it represents. Imagine that you are pointing to it on a large screen and describing it to your students or the interviewer, if that helps you.

[Hit play again. Show it again and let them talk through it. If they get flustered and want to start over, just hit play again from the beginning.]

[When they are completed with second viewing, ask them…]

5-How much time do you think is represented in this visualization? (Hours, day, weeks, years, etc.)

6-What topics or concepts would you use this visualization to teach about, if anything?

7-Have you ever used something like this before in your teaching? If so, what was it and where did you get it from (internet, DVD, etc.)?

Repeat steps 1 & 2 above for each of the five visualizations.
When you are finished, please bring them back to the main classroom. Thank you.

END OF INTERVIEW
Appendix D

Moon Formation Storyboard: Instructions and Form

**Storyboard exercise: How did we get our Moon?** (10-minute task)

**Instructions:**
- If your students asked you how we got our moon,
- Right now we have a moon in orbit about 250,000 miles from Earth that goes around every 28 days. How did it get there and why do we have a moon?
- How would you explain that story to your students? You can write, draw the story of how we got to our moon today.

Moon Formation Storyboard Data Collection Form (blank):

*How did we get our Moon?*

[Blank spaces for storyboard data collection form]
Appendix E

Instructional Plan Survey

6.1 Of these 5 visualizations, which one(s) do you plan to use in your instruction?

6.2 How will you implement it/Them?

6.3 How do you think your students will respond to the visualizations?

6.4 When will you be able to utilize one of these visualizations in your classroom?

6.5 Are there certain students in your class that might particularly benefit from instruction that includes visualizations?

6.6 Are there barriers that you face in your classroom or school setting that might hinder your usage of visualizations in your instruction?
Appendix F

Professional Development Evaluation Survey

7.1 On a scale of 1 – 5, how prepared do you feel, as a result of this professional development workshop, to incorporate scientific visualizations in your classroom instruction? Circle one:

1 – Very prepared  
2 – Prepared  
3 – Somewhat prepared  
4 – A little prepared  
5 – Not prepared

7.2 What did you like about this professional development workshop?

7.3 What would you like to have that you did not receive in this professional development?

7.4 Any other comments:
Appendix G

Visualization Implementation Report Survey

9.1. Your name?
   Open-Ended Response

9.2. What is the file name of the visualization that you used?
   Open-Ended Response

9.3. Did you play the visualization from the DVD or from the Internet?
   DVD
   Internet

9.4. What topic(s) or concept(s) did you use this visualization to teach?
   Open-Ended Response

9.5. What impact do you think the visualization had on your students?
   Open-Ended Response

9.6. What did you observe or hear from your students that led you to this conclusion about the impact on your students?
   Open-Ended Response

9.7. Did you notice any questions or feedback from your students that demonstrated to you that this visualization helped them meet the learning goals that you have for them?
   Yes
   No
   If yes, what were they?

9.8. Did you utilize any additional resources that you found useful in your personal planning or in your instruction with your students (for example Google Earth, websites, videos, etc.)?
   Yes
   No
   If so, which ones?

9.9. Based on this experience, what makes this a useful visualization for teaching and learning?
   Open-Ended Response

9.10. Were there any changes to the visualization that would have made this visualization more effective for instructional uses?
   Yes
   No
   If so, which ones?
9.11. Were there any materials or resources that would have helped you use this visualization more effectively?
    Yes
    No
    If so, which ones?

    END OF SURVEY
Appendix H

Distributed DVD: Index of Contents

Interpreting Global, Half-Hourly Cloud Observations to Promote Weather and Climate Literacy
  1. Clouds Introduction (1:15)
  2. Earth’s Orbit (0:16)
  4. Monthly Interpretations [“produced” version] (14 x 1:25)

Produced by American Museum of Natural History’s Science Bulletins
NOAA Office of Education Grant #NA06SEC469003

Index of Science Visualizations: DVD 2

- Climate and Weather
  - Carbon Monoxide.mov
  - Glaciers_feature.mov
  - Global Ozone_raw.mov
  - Global Ozone.mov
  - NAQ_feature.mov
  - Sea Ice_raw.mov
  - Sea Ice.mov
  - Sea Surface Temperature.mov
  - Seasonal plant growth.mov
  - Weather and Climate events_raw.mpg
  - Weather and Climate events.mov

- Extra Visualizations
  - Day & Night.mpg
  - Earth Satellites.mov
  - Hurricane Katrina.mov
  - Mars Rover Animation
  - Orbiting Earth.mov
  - Solar flux.mpg

- Physical Earth–Sun–Moon System
  - Earth's Magnetic Shield_raw.mov
  - Earth's Magnetic Shield.mov
  - Our Moon_raw.mov
  - Our Moon.mov

- Solar System
  - Pluto and New Horizons.mov
  - Saturn & Cassini.mov

- Visualization Index.docx
- Visualization Index.pdf
Appendix I

Package of Supporting Information for Teachers
(distributed October 2009)

Note: Links to websites, data sources and related resources have been removed from the following information due to many no longer being available.

Visualizations Included in Package

1. Weather and Climate Events
2. Earth’s Magnetic Shield
3. Sea Ice
4. Our Moon
5. Global Ozone
6. Sea Surface Temperature
7. Seasonal Plant Growth
8. Pluto and New Horizons
9. Saturn and Cassini
10. Glaciers feature
11. NAO feature: Driving Climate Across the Atlantic
12. Carbon Monoxide

1. Weather and Climate Events

Synopsis:
From a satellite's-eye view, Earth's atmosphere may seem like a chaotic swirl of clouds and currents. But patterns do emerge. Our planet’s weather results from a complex interplay between the Sun's heat and Earth's air, water, and land. The rotation of the Earth helps guide where the air-moist, dry, cool, warm-tends to circulate. Over the long term—from as short as a few weeks to as long as a century—the "average" weather and how it changes is called climate.

More About the Data:
The cloud data are collected every half-hour, day or night, from five weather satellites orbiting Earth. Their sensors measure not “clouds” per se, but infrared radiation (heat) in the atmosphere. White indicates cooler temperatures, and black indicates warmer ones. Therefore, the colder the cloud, the whiter its trace. This also explains the “shadow” that sweeps east to west across the data, called the diurnal cycle. As the Sun warms landmasses in the daytime, they darken on the data. Each sweep represents one day of the Earth orbiting the Sun.

The clouds dataset, which was developed by NOAA’s Climate Prediction Center, is the first to give scientists a whole-Earth, near-real-time view of how storm systems evolve. It is used for meteorological research, to assess weather forecasting computer models, to plan flight routes for aircraft, and, now, for public education.
2. Earth’s Magnetic Shield

**Synopsis:**
Life on Earth depends on light and heat from the Sun. But the Sun emits more than just light and heat. Tiny particles—mostly protons and electrons—stream away from the Sun in a "solar wind" that can reach speeds of more than a million kilometers an hour. See how scientists are modeling interactions between solar winds and Earth's magnetosphere, the magnetic shield generated by our planet's rotation and molten core, which protects us from the full impact of these supersonic particles.

**More on this visualization**
The solar wind flows throughout the Solar System, except where planets or their magnetic fields get in the way. Not all planets act like big magnets, but Earth does, protecting us from the solar wind’s supersonic particles.

In this visualization, speeding particles appear as streaks heading away from the Sun. Between the Sun and Earth, a shallow bowl shape represents the “bow shock,” where the solar wind slows down. Around Earth, a billowing blue surface corresponds to the outermost reaches of the magnetosphere.

Scientists use computer models to simulate the behavior of Earth’s magnetic field interacting with the solar wind. In one such model, scientists studied the effects of a 2003 "solar storm" that caused radio blackouts and satellite malfunctions. During the storm, intense pressure from the solar wind pushed the bow shock and compressed Earth’s magnetic field. Computer models help predict when the solar wind might become troublesome, knocking out satellites or endangering astronauts.

This visualization highlights data from the Center for Integrated Space Weather Modeling, which is based at Boston University. Simulated auroras were created in conjunction with the University of Alaska Fairbanks, and photographer Bryan R. White provided real imagery of auroras. This visualization also uses data from the Digital Universe Project, a collaboration of NASA and the American Museum of Natural History, to create an accurate three-dimensional map of the visible Universe. The Digital Universe, which includes dozens of datasets that are constantly updated, is free to download.

**Educator Resources:**
Exploring In-Depth
While the Sun provides the light and heat that life on Earth needs to survive, it is also the source of dangerous emissions. The Earth’s magnetic field protects Earth from this "solar wind" however, which can exceed speeds of over a million kilometers an hour. Watch the AstroViz, Earth's Magnetosphere, then use the questions below to explore topic in-depth with your class.

* What does the Sun emit besides light and heat?
* How does Earth’s magnetic field protect us from the solar wind?
* What is the “bow shock”?
* What electronic disruptions can be caused by intense solar activity?
* How can scientists predict the potential impact of future solar storms?
* Do you think there should be solar flare reports as part of the weather? Why or why not?

3. Sea Ice

**Synopsis:**
This visualization of satellite data reveals seasonal patterns and long-term trends in the distribution of sea ice across the Arctic Ocean. Arctic sea ice reaches its lowest annual extent in September, after the warmth of summer. Sea ice in September 2007 hit a record low—50 percent smaller than it was in 1979, the first September that satellites measured sea ice. The significant downward trend of sea ice seen in recent years exceeds computer-model predictions of the effects of global warming.

**More On This Visualization**

During the winter months, a layer of ice forms across vast expanses of the Arctic Ocean. Each summer, more than half of that ice vanishes. This natural cycle of freezing and thawing is influenced both by seasonal temperature variations and long-term climate change. Scientists are using satellite images to measure the distribution of Arctic sea ice to better understand how it is linked to Earth’s climate system.

Over the past few decades, the amount of sea ice in the Arctic has gradually been dwindling. While the white Arctic ice reflects the Sun’s rays back into the upper atmosphere, the surrounding water absorbs heat and increases in temperature. The warmer water continues to melt more ice, decreasing the amount of solar energy that can be reflected and increasing energy absorbed by the water. This effect, called a positive feedback loop, contributes to a trend towards warmer global temperatures.

This video illustrates both seasonal patterns and long-term changes in sea ice distribution across the Arctic Ocean. It draws data from two satellite instruments that measure emitted microwave radiation, which helps distinguish open ocean from ice. The Scanning Multichannel Microwave Radiometer recorded data on sea ice conditions from October 1978 through August 1987. The Special Sensor Microwave Imager has provided data since June 1987.

Special thanks to the National Snow and Ice Data Center and to Claire Parkinson and Nick DiGirolamo of the NASA Goddard Space Flight Center Hydrospheric and Biospheric Sciences Laboratory.

4. Our Moon

**Synopsis:**
The peaceful glow of the moonlight in our sky belies a violent history. Evidence suggests that the Moon formed when a Mars-sized object collided with the young Earth, and detailed computer models show us how such an impact could form our lunar companion in just one month.
**Educator Resources:**
Exploring In-Depth

4.6 billion years ago, the Moon was born out of a violent collision with Earth. Watch this visualization on its fiery past, and use the discussion questions below with your class.

- What cosmic event do scientists theorize happened about 4.5 million years ago?
- What caused the molten matter to concrete or come together? What formed from this concretion?
- What evidence from the Moon’s surface supports this theory?
- How do scientists know that the moon was only 14,000 miles from the Earth when it was first formed?
- What data would scientists collect in future missions to the Moon.

**5. Global Ozone**

**Synopsis:**
Ozone gas (O3) in the upper atmosphere shields Earth from the Sun's dangerous ultraviolet radiation. Since the early 1980s, scientists have been aware that manmade chlorofluorocarbons (CFCs) destroy atmospheric ozone worldwide. The greatest losses have occurred at the poles. Due to seasonal variations, the Antarctic ozone "hole" is most extreme in late September or early October. Although the average extent of the 2008 ozone hole was the fifth largest on record, ozone levels globally are slowly recovering due to the international ban on CFCs initiated by the Montreal Protocol in 1987.

This animation shows ozone measurements across the globe obtained by NASA's Total Ozone Mapping Spectrometer (TOMS) instrument and the Ozone Monitoring Instrument (OMI) aboard NASA's Aura satellite. Ozone levels are shown in measurements of dobson units. The "hole" represents ozone levels lower than 220 dobson units.

Satellites provide scientists with a daily picture of the components of the Earth system. The United States satellite measurement program for ozone, run jointly by NASA and the National Oceanic and Atmospheric Administration (NOAA), has measured ozone distribution by season, latitude, and longitude since 1978.

**6. Sea Surface Temperature**

**Synopsis:**
Long-term observation of sea-surface temperatures reveals patterns and cycles of variation caused by seasonal winds, Earth's rotation, and other factors. This video shows sea-surface temperature measurements across the globe obtained by the Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS) satellite instruments. The historical data, gathered by AVHRR from 1985 to 2002, are shown in
measurements of degrees Celsius. The current MODIS data (2002-2006), also in degrees Celsius, show deviations from long-term averages.

Satellites provide scientists with a picture of what's happening daily over the entire Earth. The United States satellite measurement program for sea-surface temperature, run by the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA), has gathered global measurements daily since 1979.

**Educator Resources:**
Exploring In-Depth

Sea surface temperatures are constantly changing. These changes affect—and are influenced by—weather and climate worldwide. By studying satellite measurements of sea surface temperatures, scientists are learning to detect and predict recurring weather patterns. Provided here are questions to help guide a discussion about sea surface temperature.

- What do the Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS) satellite instruments measure?
- What do long term observations of the sea surface temperature reveal?
- What happens every three to seven years along the equatorial Pacific?
- What impact do these higher than normal sea surface temperatures have?
- What are some of the weather related effects of El Niño?
- What might be some economic effects of El Niño?

### 7. Seasonal Plant Growth

**Synopsis:**
Scientists use satellite observations to analyze plant growth rate on land and in the ocean. Outside the tropics, plants grow faster as Earth's tilt makes light available in spring and summer. In the tropics, some regions don't have enough water to support year-round plant growth, despite an abundance of light. Light changes with the seasons, and the biosphere responds.

**Educator Resources:**
Exploring In-Depth

This data visualization illustrates the relationship between Earth's seasonal sunlight and plant growth on land and in the oceans. Examine the relationship between the seasons, growth rates, and geography, and explore the animation with your class through the questions.

* What is the main determinant of plant growth on Earth?
* How does the tilt of Earth’s axis and its orbit around the Sun create seasons?
* Why is plant growth in the tropics year-round rather than seasonal?
* Some areas of the tropics are virtually void of plants. Why and what might these regions be?
8. Pluto and New Horizons

Synopsis:
Since its discovery in 1930, we’ve looked at Pluto as our solar system’s ninth planet. But residing in the icy realm of the outer solar system, where the sun’s brightness is less than 1/1000 of the brightness here on Earth, Pluto is nothing like the other planets of our solar system. It differs tremendously from the gas giants Jupiter, Saturn, Uranus, and Neptune, but does not resemble the rocky terrestrial worlds Mercury, Venus, Earth, and Mars.

However, Pluto is not unique. In the past several years, scientists have discovered many more objects like Pluto. These objects, nicknamed “icy dwarves,” are relatively small and made mostly of ice, with orbits that are often highly elongated and steeply inclined to the plane of the solar system.

Identifying these objects is not the same as understanding them, however: even our best images of Pluto are hazy and unresolved. In order to study Pluto and the other icy dwarves of this mysterious realm we need to get closer. And we will.

On January 19, 2006, the New Horizons Mission set out on a decade-long voyage to Pluto.

Traveling at unprecedented speeds, New Horizons reached our Moon’s orbit in just nine hours—a distance that Apollo astronauts took three days to traverse. And in just 13 months, the spacecraft will encounter Jupiter, study the gas giant, and use its huge gravity to gain speed. But even traveling faster than any spacecraft ever launched, it will take another eight years to get to Pluto and its moons before proceeding into unexplored regions of the solar system, beaming back the first images from the realm of icy dwarves.

This interactive also uses data from the Digital Universe Project, a collaboration of NASA and the American Museum of Natural History, to create an accurate three-dimensional map of the visible Universe. The Digital Universe, which includes dozens of datasets that are constantly updated, is free to download at http://haydenplanetarium.org/universe/

9. Saturn and Cassini

Synopsis:
After a seven-year trip, the Cassini spacecraft arrived at Saturn in July 2004. Since then, Cassini has been capturing never-before-seen imagery of the ringed planet and its moons. By the mission’s end in July 2008, the craft will have made 70 orbits of the Saturnian system, using cameras, magnetometers, spectrometers, and radio antennas to analyze the planet’s magnetic field, composition, rings, atmosphere, and 33 moons more completely than ever before.

On January 14, the orbiter's Huygens probe descended through the murky atmosphere of Titan, Saturn's largest moon. The probe is the first in history to analyze and image Titan's atmosphere and surface characteristics.
Stop along Cassini's and Huygens's journey with the interactive at left. You can view historical images of Saturn, spy on the planet's rings, tour the Cassini orbiter, meet Saturn's moons, and learn what scientists expected to see on Titan. To visually recreate Cassini's route to Saturn, the animation uses real space data from the Digital Universe Project, a collaboration of NASA and the American Museum of Natural History. The Digital Universe includes dozens of datasets collected by the Museum and is constantly updated.

10. Glaciers feature

**Synopsis:**
Follow scientist-adventurer Lonnie Thompson to the 5,670-meter-high Quelccaya ice cap in the Peruvian Andes. Thompson and his team from Ohio State University are racing to core a cylinder of 1,500-year-old ice to unravel the past climate patterns of this region - before our gradually warming climate melts this invaluable record away. By analyzing global ice cores, glaciologists like Thompson now have a well-preserved record for 150,000 years of climate history, allowing us to better predict future climate change.

**Essays to print and share**
The Ice Plant Cometh
[http://www.amnh.org/sciencebulletins/content/e.f.glaciers.20050331/essays/52.html](http://www.amnh.org/sciencebulletins/content/e.f.glaciers.20050331/essays/52.html)

Expedition for an Ice Core
[http://www.amnh.org/sciencebulletins/content/e.f.glaciers.20050331/essays/53.html](http://www.amnh.org/sciencebulletins/content/e.f.glaciers.20050331/essays/53.html)

The Coming and Going of an Ice Age
[http://www.amnh.org/sciencebulletins/content/e.f.glaciers.20050331/essays/54.html](http://www.amnh.org/sciencebulletins/content/e.f.glaciers.20050331/essays/54.html)

Rapid Change in a Warming World
[http://www.amnh.org/sciencebulletins/content/e.f.glaciers.20050331/essays/55.html](http://www.amnh.org/sciencebulletins/content/e.f.glaciers.20050331/essays/55.html)

The Climate Jump Heard 'Round the World
[http://www.amnh.org/sciencebulletins/content/e.f.glaciers.20050331/essays/59.html](http://www.amnh.org/sciencebulletins/content/e.f.glaciers.20050331/essays/59.html)

**Educator Resources**
Exploring In-Depth

Glaciers are a valuable key to understanding the conditions of Earth in both the past and the present. Find out what clues they hold about ancient climate, as well as what they can predict about its future.

- What is an ice core?
- What elements get trapped in ice cores?
- What do ice cores tell scientists about the climate history of the Earth?
- What proof do scientists have that our climate is warming?
Why is the Quelccaya glacier unique? What has been happening to the glacier in recent decades?

Of what use is the information that scientists are collecting?

11. NOA: Driving Climate Across the Atlantic

Synopsis:
For centuries, a massive atmospheric system has regularly altered weather patterns, fishery production and animal migrations across the North Atlantic Ocean. At last, Earth scientists and climate modelers are beginning to understand how--and when - the North Atlantic Oscillation happens.

Essays to print and share
NAO Who?
http://www.amnh.org/sciencebulletins/content/e.f.nao.20040910/essays/28.html

How NAO Does Its Thing
http://www.amnh.org/sciencebulletins/content/e.f.nao.20040910/essays/29.html

NAO Data Hunting (and Gathering)
http://www.amnh.org/sciencebulletins/content/e.f.nao.20040910/essays/30.html

Forecasting the Unpredictable
http://www.amnh.org/sciencebulletins/content/e.f.nao.20040910/essays/31.html

Educator Resources
Exploring In-Depth

The NAO is a complex climate system, influencing local weather in various regions. What is the NAO, and how does it work?

- What is a positive NAO phase? What are some examples of weather conditions caused by a positive phase?
- What is a negative NAO phase? What are some examples of weather conditions caused by a negative phase?
- How do the weather patterns the NAO creates affect local economies?
- What has caused renewed interest in the NAO?

Studying the NAO requires an enormous amount of data on numerous weather and climate phenomena. What are some of the challenges in collecting this data?

- What problems do scientists run into when trying to predict a NAO trend?
- Why is having data from so many NAO’s of the past so important?
• How far back can scientists go to gather data on the NAO? Can they determine what the NAO pattern was like a million years ago?

12. Carbon Monoxide

**Synopsis:** An instrument on NASA's Terra satellite is providing the first global measurements of invisible carbon monoxide (CO) gas in the lower atmosphere, or "troposphere." The instrument is called MOPITT, which stands for "Measurement Of Pollution In The Troposphere."

**Essays to print and share:**
CO is a poisonous gas that prevents the atmosphere from filtering other pollutants. CO also helps form ozone gas, which is harmful to life when it appears in the lowest reaches of the troposphere where we get the air we breathe. About two-thirds of the world's CO comes from human activity. CO gas is produced by the burning of fossil fuels in automobiles and industry and by the burning of vegetation for agriculture and land clearing. It is also a product of natural forest and grassland fires.

CO gas persists in the atmosphere for weeks or months, allowing MOPITT to track the gas as it rises above the bottom-most layer of the atmosphere. By tracking CO plumes thousands of miles across the globe, MOPITT's data help scientists understand the local sources and global consequences of air pollution and the complex chemical changes associated with CO in the atmosphere.

This visualization shows that the Northern Hemisphere produces a steady stream of noxious CO throughout the year. Also evident are massive plumes of CO that form over central Africa and Southeast Asia following annual agricultural burning regimes. Worldwide, clouds of gas are blown and scattered by winds, leaving a trail of CO for thousands of miles downwind of industrial or agricultural burning sites. High levels of contamination are also apparent over major cities.

CO concentrations between 3 and 5 km above the Earth's surface (just above the air we breathe) are shown as eight-day running averages in parts per billion by volume (ppbv). The MOPITT teams at the University of Toronto in Canada and at the National Center for Atmospheric Research in Boulder, Colorado, provided the data from which this animation was produced. The MOPITT instrument was designed by the Canadian Space Agency as part of a collaborative effort with NASA for deployment on NASA's Terra satellite.

**Educator Resources**
Learn about the causes of increased CO levels in the lower atmosphere and discuss how the information can play a role in constructing environmental policy.

• What does the data visualization on global carbon monoxide emissions show?
• What is carbon monoxide?
• Can increased amounts of carbon monoxide in the atmosphere pose a threat? How?
• What are the three major sources of carbon monoxide?
• Why is the data showing the concentrations of carbon monoxide in the atmosphere important to scientists?