UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

THREE-DIMENSIONAL PEDAGOGICAL CONTENT KNOWLEDGE: UNDERSTANDING SCIENCE LEARNING IN THE NEXT GENERATION OF SCIENCE EDUCATION

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

In fulfillment of the requirements for the

Degree of

DOCTOR OF PHILOSHOPHY

By

QUENTIN LEE BIDDY
Norman, Oklahoma
2018

THREE-DIMENSIONAL PEDAGOGICAL CONTENT KNOWLEDGE:
UNDERSTANDING SCIENCE LEARNING IN THE NEXT GENERATION
OF SCIENCE EDUCATION

A DISSERTATION APPROVED FOR
THE DEPARTMENT OF INSTRUCTIONAL LEADERSHIP AND ACADEMIC CURRICULUM

BY

Dr. Timothy Laubach, Chair

Dr. Edmund Marek

Dr. Stacy Reeder

Dr. Kerry Magruder

Dr. Crag Hill

Acknowledgment

First and foremost, I would like to thank my family. Stacey, Nickolas, and Jewel, without your constant love, support, and encouragement I would not be able to make it this far. Stacey, you are my best friend and biggest source of encouragement. Thank you for believing in and supporting me and our family on this journey. I love you and am so excited to start the next chapter of our family together. I would also like to thank my K20 family. At K20 I have truly come to know and experience what shared leadership and collaboration looks and feels like. Janis and Pat, you are only my colleagues and friends, but my "work moms". Dr. Atkinson, Janis, Pat, and Heather thank you for showing my what it means to be a team working toward a common goal. Your passion to help teachers realize their full potential for their students inspires me. Dr. Atkinson, thank you for taking the chance on bringing 3-Dimensional Learning to the rural teachers of Oklahoma and on our team. I am grateful for your trust in me and our team. Dr. Laubach, I would like to thank you especially for your guidance, support, and friendship as I have progressed along this journey. Thank you for helping me know what it means to be an academic and scholar while maintaining balance with family and friends and retain a sense of who I am through the process. Finally, I would like to thank all of the teachers involved in the CORPS project. Each of you have inspired me to see that what we do makes an impact on the students you serve. Keep up the good work, fight the good fight. I truly believe that you are making a significant difference for future generations.

Table of Contents

List of Tables

List of Figures

Abstract

This study focused on examining the pedagogical content knowledge (PCK) of teachers focused on transitioning to phenomena-driven, three-dimensional Learning as outlined in *A Framework for K-12 Science Education* (NRC, 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013). This study utilized a mixed methods explanatory sequential design (Creswell, 2013; Creswell & Clark, 2018) to develop and carry out this two-phased study. Phase One included quantitative data collection and analysis and Phase Two included qualitative data collection and analysis. At the national level, 19 states have adopted the NGSS (National Science Teachers Association, 2018). A number of other states have utilized the NGSS and A Framework for K-12 Science Education to develop three-dimensional standards similar to the NGSS (National Association of State Boards of Education, 2018). This study takes place in a state transitioning to three-dimensional standards similar to the NGSS.

PCK, an idea first formed by Lee S. Shulman (1986), is the ability of a teacher to take specific content knowledge about their discipline and craft it into meaningful and powerful learning opportunities for students (Kind, 2009). PCK is the “tacit, hidden knowledge” (Kind, 2009, p. 3) of a teacher that lies at the crossover between teacher content knowledge, teacher pedagogical knowledge and teacher contextual knowledge. The National Research Council (1996) identified PCK as “the knowledge that differentiates a scientist from a science teacher” (in Demird.ğen, 2016, p. 496).

Through a mathematics and science partnership (MSP) grant program focused on improving teacher content knowledge, pedagogical knowledge, and pedagogical content knowledge centered on 3D Learning and Teaching, 67 grades 3 through high school biology teachers from 18 rural school districts worked to transition to phenomena-driven three-dimensional instruction. Teachers needed to develop PCK that is specific to 3D Learning and Teaching or what could be described as Three-dimensional Pedagogical Content Knowledge (3D-PCK). Teachers need to understand the three dimensions, SEPs, CCCs, and DCIs, of the NGSS (NGSS Lead States, 2013), and they will also need to understand how to integrate the three-dimensions seamlessly in instruction so students are actively utilizing all three dimensions to make meaning and construct explanations for natural phenomena (Allen & Penuel, 2015; Bybee, 2013; Moulding et al., 2015; NASEM, 2015; Reiser, 2013). This new form of PCK would look different from PCK found in traditional science classrooms and would have characteristics directly related to 3D Learning and Teaching.

Findings show that the teachers involved in the study were able to increase their understanding and implementation of 3D Learning. Additionally, 3D-PCK was a useful construct for uncovering and describing areas of teacher growth related to 3D Learning. Through this study the evidences of growth in understanding and implementation of 3D Learning, the growth structures supporting this growth, and the motivations driving this growth in the participating teachers was identified.

Chapter 1: Introduction

Science teachers across the United States are currently in the process of transitioning or preparing to transition to new standards that are more complex in nature than most previous science standards requiring teachers to align their instructional practices to utilize and integrate three dimensions of science learning [National Research Council (NRC), 2012; NGSS Lead States, 2013]. When transitioning to new ways of thinking about learning and teaching, teachers may have to change their orientations to the three domains of teaching. And for some, this can require a significant shift in instructional practices (Gess-Newsome, 2015; Reiser, 2013). Like most professions, teaching requires a specific set of skills and knowledge. Developing these types of skills and knowledge can be further complicated when teachers transition to new modes of teaching, such as called for with the *Next Generation Science Standards* (NGSS Lead States, 2013). However, teaching is a unique profession. Teachers must possess the necessary content knowledge for their disciplines, while also having the pedagogical skills to engage their students in meaningful learning experiences with this content, in addition to knowing their students and their cultures and community (Shulman, 1986). This study seeks to bring together these two areas of research, three-dimensional learning [National Research Council (NRC), 2012] and pedagogical content knowledge (PCK) (Shulman, 1986, 1987, 2015).

Three-Dimensional Learning and Teaching

Teachers are currently in the process of attempting to transition to the *Next Generation Science Standards* (NGSS Lead States, 2013) or similar science education standards based on the recommendations outlined in the *A Framework for K-12 Science Education* (NRC, 2012). In the Summer of 2011, 26 lead states in collaboration with Achieve, the National Research Council, the National Science Teachers Association, and the American Association for the Advancement for Science began the process of developing the *NGSS* to address the need for guiding and aligning science instruction to the most current research. *NGSS* development occurred through an iterative process going through numerous drafts and revision based on multiple stakeholder feedback. The final draft was released in April 2013 (NGSS Lead States, 2013).

At the national level, 19 states have adopted the *NGSS* (National Science Teachers Association, 2018). A number of other states have utilized the *NGSS* and *A Framework for K-12 Science Education* to develop three-dimensional standards similar to the *NGSS* (National Association of State Boards of Education, 2018). This study takes place in a state transitioning to three-dimensional standards similar to the *NGSS*. Teacher in this state are at different stages of transitioning to three-dimensional learning and teaching, and there are many initiatives that have been put in place to assist teachers in this transition. This study took place within the context of a three-year project focusing on helping teachers, grade 3 through high school, develop the skills and knowledge to successfully implement the vision of these new standards in their classrooms.

The vision of these new science standards is for students to actively engage in the practices of science and engineering as they ask questions and investigate natural phenomena centered around a set of core science ideas as they progress from kindergarten to twelfth grade (NRC, 2012). To achieve this vision, two goals were put forth: “(1) educating all students in science and engineering and (2) providing the foundational knowledge for those who will become the scientists, engineers, technologists, and technicians of the future" (NRC, 2012, p 10.). The main focus of these new recommendations center on science learning and teaching and hinges on the ability of teachers to develop an understanding of the three dimensions of science: science and engineering practices (SEPs), crosscutting concepts (CCCs), and disciplinary core ideas (DCIs).

To realize this vision of science learning, practicing teachers will need ongoing professional development and support [National Academies of Sciences, Engineering, and Medicine (NASEM), 2015; NRC, 2012]. These three dimensions are intended to be seamlessly integrated in instruction and assessment (Moulding, Bybee, Paulson, & Pruitt, 2015; NASEM, 2015; NRC, 2012). This integration is expressed in the way that the new standards are written as performance expectations (PEs) that are specific combinations of the three dimensions and intended to be utilized as assessment standards (Krajcik, 2015; Moulding et al., 2015; NRC, 2012).

This type of learning can be referred to as 3-dimensional (3D) Learning (Krajcik, 2015). In essence, 3D Learning encompasses three components (SEPs, CCCs, and DCIs), which work together to facilitate deeper understanding of science concepts for students. The eight SEPs can be thought of as what students engage in (e.g. such as asking questions and engaging in argument from evidence) during the process of collecting and communicating information. The DCIs are the key science ideas that students can use in conjunction with the SEPs and the CCCs to construct valid explanations for natural phenomena (Krajcik, 2015; NRC, 2012). Students utilize the seven CCCs, the lens through which scientists commonly view the world (e.g. looking for patterns or identifying cause and effect relationships) to think and reason through the data and information they collect in order to construct explanations for natural phenomena (e.g. observable objects or real events, familiar or unusual, that can be explained using big science ideas and can be investigated using the SEPs, CCCs, and DCIs).

In order for students to learn and apply the big science ideas they must use the three dimensions together (Krajcik, 2015; NRC, 2012). Essentially, teachers should not revert to the traditional ways in which they were taught through passive instruction but should instead use the science processes to engage students in actively investigating observable phenomena using the practices and processes of science and engineering (Moulding et al., 2015).

Statement of the Problem

The instruction and learning called for with 3D Learning is quite different from learning called for in older versions of science reforms and standards (NASEM, 2015; NRC, 2015). Substantial changes to classroom instruction will be required. For example, with 3D Learning, the focus is shifted from just knowing about a science concept to being able to explain how or why a science concept works with a given phenomenon (NRC, 2015). This means that teachers should move students beyond simply knowing key ideas because they are important, to facilitating students in understanding key ideas in science in order to use them to explain natural phenomena (Krajcik, 2015; Passmore & Svoboda, 2012; Reiser, 2013).

Three-dimensional Learning and Teaching moves past rote memorization of facts to application and explanation of science ideas as seen in the natural and engineered world. Even as teachers begin implementing 3D Learning and Teaching there are challenges that have and will arise as teachers move forward in this endeavor because shifts to 3D Learning-focused teaching will be significant for many teachers (Reiser, 2013). Teachers will need to understand each of the three dimensions as well as how they should be integrated together in both instruction and assessment (NASEM, 2015; NRC, 2012, 2015).

PCK is a powerful idea for uncovering the tacit ideas and characteristics behind teachers' educational decisions and philosophies and could serve as a useful framework for both pre-service and in-service teacher professional development (Shulman, 2015). PCK research has been active since Shulman first proposed PCK as a construct (Shulman, 1986). However, it has in some ways been “closeted in the world of academia…and not used by teachers concerned with improving their science teaching” (Bertram & Loughran, 2012, p. 1027). Teachers transitioning to 3D Learning and Teaching will need support (NRC, 2012; Reiser, 2013) as there is a specific body of knowledge associated with the three dimensions and how they are integrated into instruction and assessment, and with understanding and knowing why and how to implement them (NASEM, 2015; NRC, 2015). Knowing how to implement and integrate the SEPs, CCCs, and DCIs as necessary elements of 3D instruction are a part of any competent science teacher (NRC, 2012, 2015; Osborne, 2014). For teachers to be effective in phenomena-driven 3D Learning-focused teaching, new PCK models should include the three dimensions outlined in the Framework and the NGSS (Gess-Newsome, 2015).

Background and Need

The study took place in a state in the southwest region of the United States, in a professional development program for elementary and secondary in-service teachers transitioning to new standards built on the foundation of 3D Learning (NRC, 2012). Through a mathematics and science partnership (MSP) grant program focused on improving teacher content knowledge, pedagogical knowledge, and pedagogical content knowledge centered on 3D Learning and Teaching, 67 grades 3 through high school biology teachers from 18 rural school districts worked to transition to phenomena-driven three-dimensional instruction.

In this context, teachers needed to develop PCK that is specific to 3D Learning and Teaching or what could be described as Three-dimensional Pedagogical Content Knowledge (3D-PCK). Not only will teachers need to understand each individual dimension, SEPs, CCCs, and DCIs, of the *NGSS* (NGSS Lead States, 2013), but they will also need to understand how these dimensions work together and can be integrated seamlessly so that students are actively utilizing all three dimensions to make meaning and construct explanations for natural phenomena (Allen & Penuel, 2015; Bybee, 2013; Moulding et al., 2015; NASEM, 2015; Reiser, 2013). This new form of PCK would look different from PCK found in traditional science classrooms and would have characteristics directly related to 3D Learning and Teaching.

Purpose of this Study

The purpose of this study is to capture and describe the characteristics of teachers' PCK in a 3D context. This present study was designed to investigate the experiences and characteristics of a group of 67 third grade through high school science teachers actively engaged in transitioning to 3D Learning while participating in a three-year professional development program focused on supporting these teachers in this specific transition. This study focused on the first year of this program and utilized a two-phased mixed-methods approach in which quantitative data were used to select the participants for the second qualitative phase (Creswell, 2013). During the first phase, quantitative data collected from two surveys were analyzed to determine which participants showed significant growth in their understanding and reported use of 3D Learning. From this group of teachers, a small subset of participants was purposely selected for the second phase. The second phase utilized qualitative data collected from teacher instructional artifacts, lesson study observations and associated debrief interviews, and end-of-year follow-up interviews to document these teachers' experiences through the projects and classroom implementation of 3D Learning.

Through this study, two areas of research will crossover to create a new framework entitled 3D-PCK that may be used for examining practicing teachers and their teaching beliefs. 3D-PCK could be a useful framework to study 3D Learning. This research could provide insight into teachers' understanding and implementation of 3D Teaching and student learning as they transition to these new science and engineering standards.

Research Questions

This research focused on examining teacher knowledge and practices related to two areas within science education: pedagogical content knowledge (PCK) (Shulman, 1986, 2015) and phenomena-driven three-dimensional learning and teaching (3D Learning) (Krajcik, 2015; NRC, 2012). At the intersection of these two domains lies my possible research questions.

1. What are the characteristics of teachers identified with significant growth in *understanding* of 3D Learning?

2. What are the characteristics of teachers identified with significant growth in the *implementation* of 3D Learning?
3. How does teachers' 3D-PCK translate into their classroom instructional practices?
4. What experiences within the first year of a three-year 3D Learning-focused professional development context can lead to growth in teachers' understanding and implementation of 3D Learning?
5. What perceived outcomes resulted from participation in a 3D Learning-focused professional development program?

Teachers moving to new types of student learning centered on using phenomena to integrate the three dimensions of science outlined in *A Framework for K-12 Science Education* (2012) and the *NGSS* (NGSS Lead States, 2013) will need to develop PCK that is specific to these new modes of thinking, teaching, and learning. PCK in a 3D Learning environment, 3D-PCK, would look much different than PCK found in traditional classroom settings. Answering the proposed research questions could provide further insight into the future of PCK. My hope is that this research will help teachers and those that support them in this transition to continue to improve their craft and succeed in achieving the aims and goals of science education as outlined in *A Framework for K-12 Science Education* (NRC, 2012).

Summary

Recent reforms in science education require teachers to transition to new modes of thinking about instruction and learning. Both *A Framework for K-12*

Science Education (NRC, 2012) and the *NGSS* (NGSS Lead States, 2013) emphasize student learning by engaging in the practices of science and engineering while utilizing crosscutting concepts and disciplinary core ideas to construct explanations for natural phenomena. To accomplish this goal, science teachers will need to develop new forms of PCK, the idea posited by Shulman (1986) describing the hidden knowledge of teachers, which would be described differently than PCK in traditional science classrooms. New forms of PCK would explicitly acknowledge 3D instruction and could describe the characteristics of thinking, teaching, and learning associated with this type of education. The term chosen for this study to identify this new type of pedagogy is three-dimensional pedagogical content knowledge (3D-PCK).

Chapter 2: Literature Review

In seeking to understand pedagogical content knowledge (PCK) and what PCK looks like in the context of phenomena-driven three-dimensional learning and teaching (3D Learning), it may be effective to search for relevant research and information regarding PCK within a science context and 3D Learning, looking specifically for places where these two fields might intersect. Such a search provided conceptual and empirical literature about PCK such as Shulman's seminal articles: *Those Who Understand: Knowledge Growth in Teaching* (1986); *Knowledge and Teaching: Foundations of the New Reform* (1987); and *PCK: Its Genesis and Exodus* (2015). The latter publication gives insight into the origins of PCK and how it has evolved.

This search also led to additional resources of information regarding PCK within a science education context such as *Examining Pedagogical Content* Knowledge (Gess-Newsome, 1999) and *Re-examining Pedagogical Content Knowledge in Science Education* (Berry, Friedrichsen, & Loughran, 2015). These two books are collaborations between researchers in the field of PCK in which current research and positions regarding PCK were published. The more recent book *Re-examining Pedagogical Content Knowledge in Science Education* (Berry et al., 2015) is a result of a PCK Summit held in 2012 and contains research that looks at what the future of PCK could be in relation to the *NGSS* (NGSS Lead States, 2013).

Further searching for research surrounding PCK and 3D Learning, PCK and *NGSS*, Pedagogical Content Knowledge and Science and Engineering

Practices /Disciplinary Core/Crosscutting Concepts Ideas yielded some research studies which intersects both PCK and 3D Learning (Gess-Newsome, 1999; Magnusson, Krajcik, & Borko, 1999; NRC, 2012; NGSS Lead States, 2013; Shulman, 1986, 2015). However, at that time of this study, there was little research available that explored PCK in the context of NGSS and 3D Learning. Most publications discussing PCK and *NGSS* were written at the same time that *NGSS* was being developed and implemented in classrooms, and the ideas related to PCK contained within were developed in parallel to the ideas of 3D Learning. The fact that most of the current PCK ideology and research has been developed both before and during the development of the foundation of 3D Learning provides a unique opportunity for PCK research in contexts that have not previously existed.

When looking at existing PCK research, themes emerged which were used to categorize PCK literature into relevant lines of thought for this study. These themes are as follows:

1. Historical and conceptual perspectives of PCK: pedagogical content knowledge; the evolution of PCK models and components; new iterations of PCK;
2. Empirical PCK in education research; and
3. PCK in the next generation of science education.

This way of grouping the research seemed logical by starting large scale (e.g. What is PCK?) and narrowing down to a particular focus (PCK and 3D Learning). These themes are described in more detail in the following sections.

Historical and Conceptual Perspectives of PCK

What are the characteristics that come together to make a teacher a teacher? To go even further, what distinguishes effective teachers in each domain of education? Teaching is a complex endeavor which requires the teacher to apply many different types of knowledge (Magnusson et al., 1999). Most people generally assume that to be a good teacher you simply need to know more content and that teachers possess some expertise in their content (Kind, 2009; Shulman, 1986). Although content knowledge is very important, other forms of knowledge are important as well. PCK offers a way to think about these other forms of knowledge. PCK is the ability of a teacher to take specific content knowledge about their discipline and craft it into meaningful and powerful learning opportunities for students (Kind, 2009). PCK is an idea first formed by Lee S. Shulman (1986). According to Shulman (1986), PCK is the intersection of content and pedagogy "that is uniquely the providence of teachers, their own special form of understanding" (p. 8).

In the late 1950's Lee Shulman was an undergraduate at the University of Chicago taking classes with Professor Joseph Schwab. They began to discuss the constructs of subject matter knowledge, how knowledge is organized, and how the way knowledge is organized within a discipline relates to how individuals come to a specific discipline (Shulman, 2015). Schwab and his colleagues were arguing about what constituted a specific discipline such as biology, because if you cannot agree on what something is, it is difficult to design curriculum for it (Shulman, 2015). This is the same with understanding

PCK. In order for PCK to be effectively utilized as a classroom tool available to practicing teachers, we have to understand and agree on what it is and what it entails.

In the early 1970's, Shulman was researching physicians and how they go about solving problems and employing thinking strategies in the process of making medical diagnoses. The knowledge, thinking strategies, and practices utilized in this process were specific to this particular field and profession. Shulman (1986) termed this "domain specific knowledge." The idea of domain specific knowledge would include "signature pedagogies" or the "profession specific modes of teaching" that are directly related to learning to be in a specific field (e.g. doctor, lawyer, electrician, etc.). To put it in the context of science education, individuals would learn to think like a scientist or to learn what it means to think like an engineer. For each specific profession or domain, there is a set of habits of mind, heart, and practice (Shulman, 2015). This idea of domain specific knowledge would be the precursor to what would later become the idea of PCK.

By the mid 1970's, Shulman and his associates at Michigan State University were considering questions related to how teachers make pedagogical decisions. They began to apply the ideas of domain specific knowledge to decision making and pedagogical reasoning that occurs in the practice of teaching (Shulman, 2015). To this point, these questions had been viewed through the lens of cognitive psychology of learning from the perspective of the learner (Shulman, 1986). PCK shifted the viewpoint to encompass the habits of mind, heart, and practice required in the process of planning and carrying out instruction in a specific discipline.

Deeply connected to these ideas was the debate about teaching as a profession and if teachers were only workers with a set of technical skills or if they could be thought of and treated as professionals with their own autonomy able to make logical informed decisions regarding their own practices similar to a lawyer and doctor (Kind, 2009). To some degree this debate is still occurring today as teachers are more frequently being required by administrators, politicians, and reforms to teach specific curricula and utilize instructional methods that may not align with their teaching beliefs. Shulman saw teachers as a group of professionals who “develop a body of understanding that is so special and so unique that they deserve to be treated as professionals around them, with respect, with autonomy, and yes, with compensation” (Shulman, 2015, p. 11).

So, how is, what teachers know and do, different than what any subject matter expert knows and does? Regarding PCK, other researchers have asked, “What is it that a mathematics teacher can do and understand that a history teacher can’t?” (Friedrichsen, Driel, & Abell, 2011, p. 359). PCK, birthed in cognitive psychology, seeks to improve teacher assessment, teacher preparation programs, teacher professional development, and education reforms (Magnusson et al., 1999).

What exactly is PCK? For many it has been difficult to figure out what exactly the individual pieces are that make up PCK. PCK is “tacit, hidden knowledge" (Kind, 2009, p. 3). Teachers need to know their specific content, but content knowledge alone does not make a good teacher. Content knowledge does not automatically translate into classroom practice (Gess-Newsome, 2015). The National Research Council (1996) identified PCK as "the knowledge that differentiates a scientist from a science teacher" (in Demirdöğen, 2016, p. 496). None of these descriptions gives us a clear definition of PCK.

Shulman (1987) defined PCK as:

> …the distinctive bodies of knowledge for teachers. It represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to diverse interests and abilities of learners, and presented for instruction. PCK is the category most likely to distinguish the understanding of the content specialist from that of the pedagogue. (p. 8)

PCK goes beyond a thorough understanding of a specific subject (content knowledge) and knowledge of instructional methods and strategies (pedagogical knowledge). The point where these two domains crossover, where a science or math teacher is able to use their expertise as an educator to facilitate students to engage with, understand, and apply specific conceptual knowledge, this is where PCK exists (Adams & Krockover, 1997; Juhler, 2016; Kind, 2009; Magnusson et al., 1999). This is where models can be useful in helping us describe PCK more accurately as emphasized by Gess-Newsome (1999) "Good models, like good theories, organize knowledge in new ways, integrate previously disparate findings, suggest explanations, stimulate research, and reveal new relationships" (p. 3).

Shulman (1986) proposed three types of content knowledge: (a) subject matter content knowledge, (b) curricular knowledge, and (c) pedagogical content knowledge. Content knowledge pertains to knowledge and information related to a specific subject and the associated knowledge. Curricular knowledge refers to "the variety of instructional materials" available for use in different educational circumstances and how and why to use them (Shulman, 1986, p 10.). The third type of knowledge Shulman proposed, pedagogical content knowledge, is knowledge about how to effectively use these types of knowledge together to help students successfully learn in a specific discipline (Juhler, 2016). Shulman (1986) expanded on the role of PCK:

> …beyond knowledge of subject matter to the dimension of teaching, that particular form of content knowledge that embodies the aspects of content most germane to its teachability. PCK includes understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons. (p. 9)

The idea of PCK proposed by Shulman was later elaborated upon by Grossman (1990), where he included three elements: (a) Subject matter knowledge, (b) General knowledge, and (c) Knowledge of content and PCK (Friedrichsen et al., 2011). This model was elaborated on by Gess-Newsome

(1999) setting the knowledge needed for classroom teaching, PCK, at the intersection of content knowledge, pedagogical knowledge, and contextual knowledge (see Figure 1). This model will be revisited in the context of 3D Learning and Teaching in a later section of this chapter.

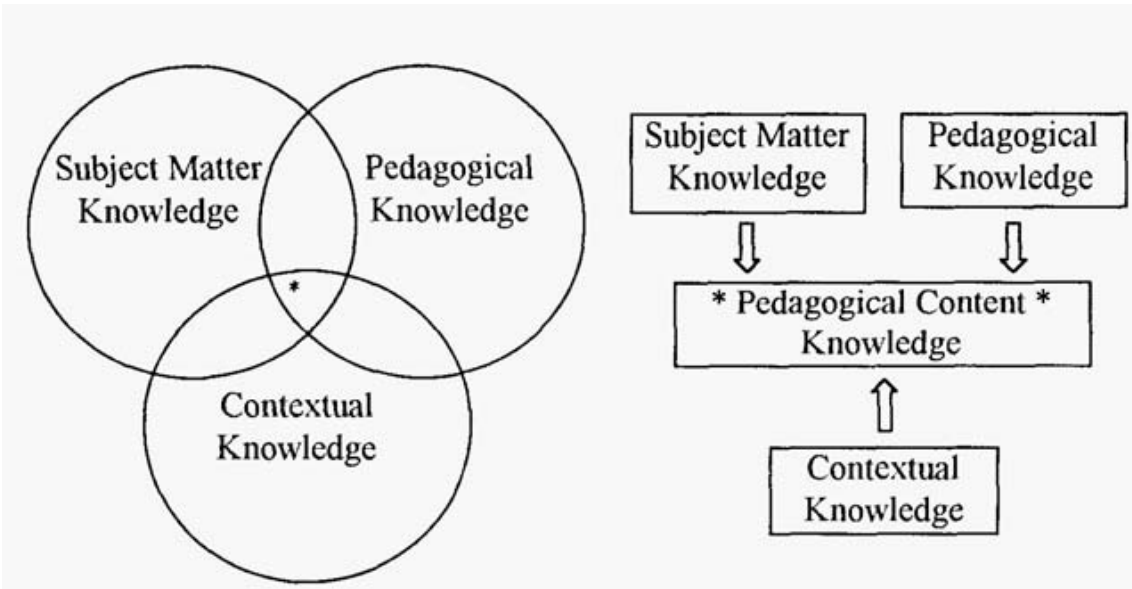


Figure 1. Two models of teacher knowledge. Reprinted from "Pedagogical Content Knowledge: An Introduction and Orientation" by Gess-Newsome, J., 1999, *Examining Pedagogical Content Knowledge*, p. 22. Copyright 1999 by Kluwer.

The most cited PCK model (see Figure 2) utilized in most PCK research was crafted by Magnusson, Krajcik, and Borko (1999). In this model Magnusson et. al. (1999) proposed that PCK contains five components: (a) Orientation to Science Teaching, (b) Knowledge of Science Curricula, (c) Knowledge of Students' Understanding of Science, (d) Knowledge of Instructional Strategies, and (e) Knowledge of Assessment of Scientific Literacy. The last four components in this model are filtered and/or amplified through a teacher's orientation and goals for science education. According to Magnusson et. al. (1999) there are nine teaching orientations: (a) Process, (b)

Academic Rigor, (c) Didactic, (d) Conceptual Change, (e) Activity Driven, (f) Discovery, (g) Project Based, (h) Inquiry, and (i) Guided Inquiry. Each of these teaching orientations has its own goals and characteristics (see Table 1). Thus, it is proposed that the teaching orientations held and practiced by a teacher shape the other four components of PCK (Magnusson et al., 1999).

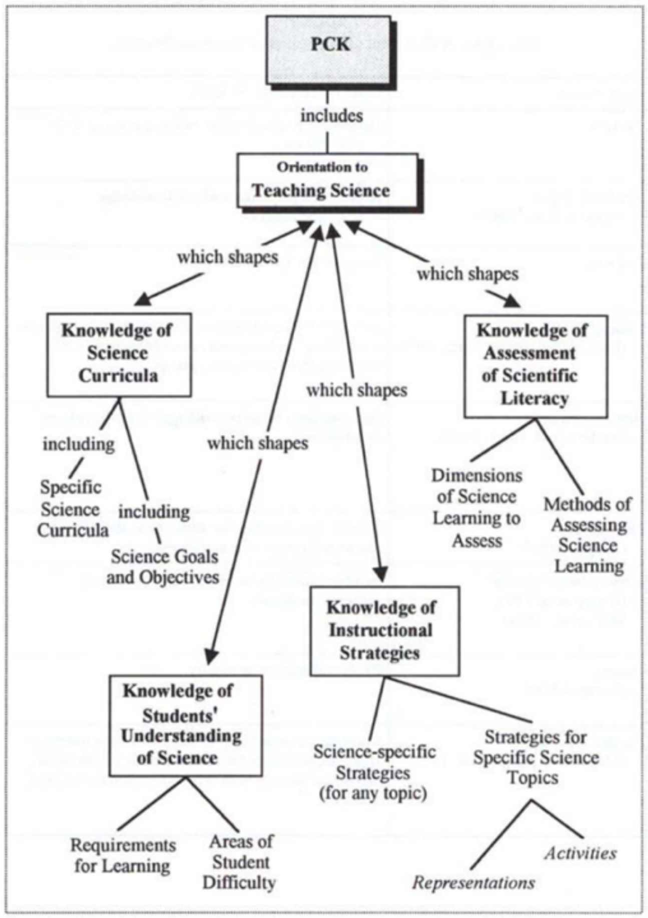


Figure 2. Components of pedagogical content knowledge for science teaching. Reprinted from "Nature, sources, and development of pedagogical content knowledge for science teaching" by Magnusson, S. Krajcik, J., & Borko, H, 1999, *Examining Pedagogical Content Knowledge*, p. 99. Copyright 1999 by Kluwer.

Magnussen et. al. (1999) further contributed to Shulman's ideas about PCK by adding teacher orientations as an overarching idea (Juhler, 2016). Likewise, the model proposed by Magnussen et. al. (1999) was science-specific and also added a new component, the knowledge and beliefs of assessment of scientific literacy (Friedrichsen et al., 2011).

Table 1

Science Teaching Orientations, Instructional Goals, and Instructional Characteristics

TEACHING ORIENTATION	GOALS	CHARACTERISTICS
Process	Help students develop the "science process skills."	Teacher introduces students to the thinking processes employed by scientists to acquire new knowledge. Students engage in activities to develop thinking process and integrated thinking skills.
Academic Rigor	Represent a particular body of knowledge (e.g., chemistry, biology, etc.).	Students are challenged with difficult problems and activities. Laboratory work and demonstrations are used to verify science concepts by demonstrating the relationship between particular concepts and phenomena.
Didactic	Transmit the facts of science.	The teacher presents information, generally through lecture or discussion, and questions directed to students are to hold them accountable for knowing the facts produced by science.
Conceptual Change	Facilitate development of scientific knowledge by confronting students with contexts to explain that challenge naive conceptions.	Students are pressed for their views about the world and consider the adequacy of alternative explanations. The teacher facilitates discussion and debate necessary to establish valid knowledge claims.
Activity Driven	Have students be active with materials; "hands-on" experiences.	Students participate in "hands-on" activities used for verification or discovery. The chosen activities may not be conceptually coherent if teachers do not understand the purpose of particular activities and as a consequence omit or inappropriately modify critical aspects of them.
Discovery	Provide opportunities for students on their own to discover targeted science concepts	Student-centered. Students explore the natural world following their own interests and discover patterns of how the world works during their explorations.
Project-based Science	Involve students in investigating solutions to authentic problems.	Project-centered. Teacher and student activity centers around a "driving" question that organizes concepts and principles and drives activities within a topic of study. Through investigation, students develop a series of artifacts (products) that reflect their emerging understandings.
Inquiry	Represent science as inquiry	Investigation-centered. The teacher supports students in defining and investigating problems, drawing conclusions, and assessing the validity of knowledge from their conclusions.
Guided Inquiry	Constitute a community of learners whose members	Learning community-centered. The teacher and students participate in defining and investigating

	share responsibility for understanding the physical world, particularly with respect to using the tools of science.	problems, determining patterns, inventing and testing explanations, and evaluating the utility and validity of their data and the adequacy of their conclusions. The teacher scaffolds students' efforts to use the material arid intellectual tools of science, toward their independent use of them.

Note. Adapted from "Nature, sources, and development of pedagogical content knowledge for science teaching" by Magnusson, S. Krajcik, J., & Borko, H, 1999, *Examining Pedagogical Content Knowledge*, pp. 100-101. Copyright 1999 by Kluwer.

Magnussen et. al. (1999) also used the PCK model to construct an additional model to represent which components underneath teacher orientations were being most emphasized (see Figure 3). Friedrichsen, Van Driel, and Abell (2011) introduced a variation which rooted the teachers' orientations into their belief systems (in Demirdöğen, 2016).

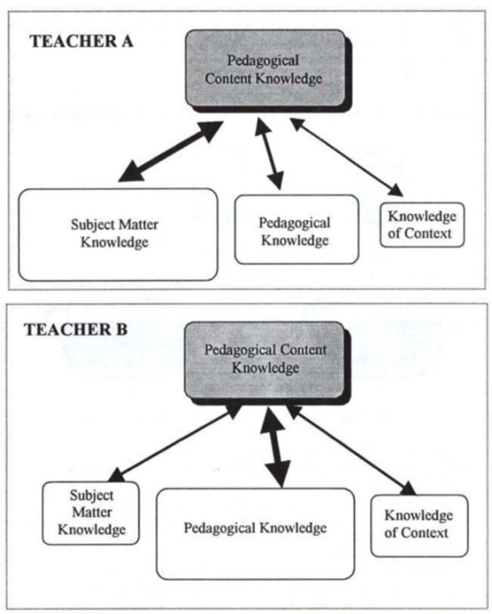


Figure 3. Emphasis of PCK components by Teachers. Reprinted from "Nature, sources, and development of pedagogical content knowledge for science teaching" by Magnusson, S. Krajcik, J., & Borko, H, 1999, *Examining Pedagogical Content Knowledge*, p. 119. Copyright 1999 by Kluwer.

In relating PCK to the science and engineering practices, Osborne (2014) described PCK as:

> (a) knowledge of the potential of specific tasks for learning, their goals and purposes, their cognitive demands and the prior knowledge they require, their effective orchestration in the classroom, and the long-term sequencing required to learn the procedural and epistemic features of science. (b) knowledge of common student misconceptions and how they affect student outcomes. (c) knowledge of a repertoire of explanations for the major ideas of science, their inherent complexity, and ways of illuminating the disciplinary nature of science. (p. 192)

Despite the usefulness of the different PCK models, they have some limitations. Shulman (2015) along with other educational researchers at the 2012 PCK summit were able to identify some of these limitations:

- “It was devoid of emotion, affect, feelings, and motivation, all of the non-cognitive attributes. This is such an important piece (Shulman, 2015, p. 9)”
- “It didn’t attend sufficiently to pedagogical action (Shulman, 2015, p. 10)”
- “PCK must also be pedagogical context knowledge, e.g. social and cultural context (Shulman, 2015, p. 10)"
- “Too many ideas were packed into PCK (Gess-Newsome, 2015, p. 30).”
- PCK was generalized (Gess-Newsome, 2015, p. 36).

While at the PCK Summit, the educational researchers were tasked with the possibility of creating a new model of PCK that could unify the field of PCK research (Gess-Newsome, 2015). This new model (see Figure 4) added new facets to understanding and viewing science teaching such as a new development called professional knowledge, described as containing seven components: (a) Content Knowledge, (b) General Pedagogical Knowledge, (c) Curriculum Knowledge, (d) **Pedagogical Content Knowledge**, (e) Knowledge of Learners and Their Characteristics, (f) Knowledge of Educational Contexts, and (g) Knowledge of Educational Ends, Purposes, and Values (Kirschner, Borowski, Fischer, Gess-Newsome, & von Aufschnaiter, 2016). This addition expands on Shulman's original definition of knowledge surrounding PCK.

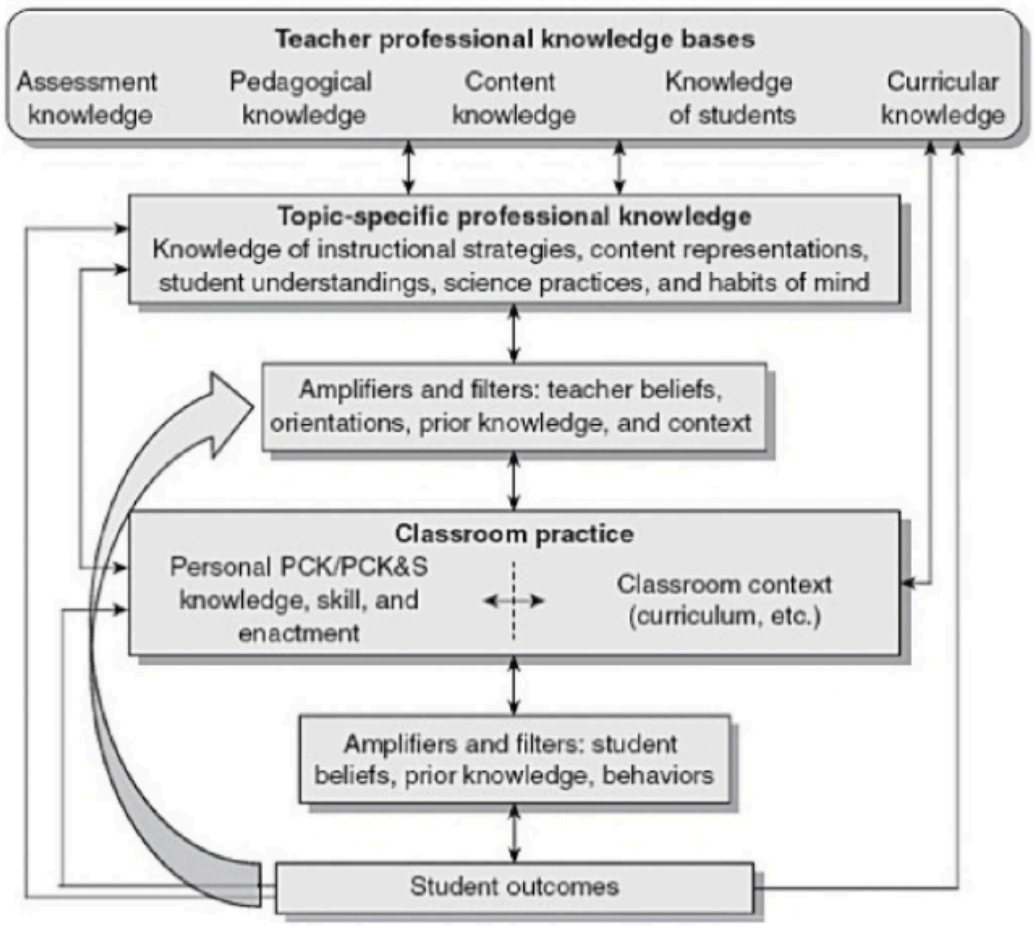


Figure 4. Model of teacher professional knowledge and skill (TPK&S) including PCK and influences on classroom practice and student outcomes. Reprinted from "A model of teacher professional knowledge and skill including PCK" by Gess-Newsome, J., *Re-examining pedagogical content knowledge in science education*, p. 31. Copyright 2015 by Routledge.

This new model of teacher professional knowledge and skill (TPK&S) sets teacher professional knowledge and the associated knowledge bases (Assessment Knowledge, Pedagogical Knowledge, Content Knowledge, Knowledge of Students, and Curricular Knowledge) as the overarching role and places PCK within this model. Underneath and in relationship with these knowledge bases is Topic-Specific Professional Knowledge (TSPK) which is specific to a teaching context. TSPK can include things like “choosing effective instructional strategies, understanding student knowledge and misconceptions, knowing how to integrate science and engineering practices, crosscutting concepts, and the nature of science” (Gess-Newsome, 2015). Underneath TSPK lies teacher amplifiers and filters, things which either strengthen or narrow teacher professional knowledge. These can be things such as a teacher’s individual beliefs, teacher orientations, prior knowledge, and the context of the learning experience. These amplifiers and filters directly affect what occurs in classroom practice (Gess-Newsome, 2015).

Classroom practice, where PCK is located in this model, is the place where all of the previously mentioned components are enacted and expressed during the planning and carrying out of classroom instruction. Thus, the researchers at the PCK Summit described PCK as “the application of knowledge to teaching which can be found in the instructional plans that teachers create and in the reasons behind their instructional decisions” (Gess-Newsome, 2015, p. 36). They identified two types of PCK:

1. Personal Pedagogical Content Knowledge (PCK): "***The knowledge of, reasoning behind, and planning for*** teaching a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes (Reflection on Action, Explicit)" (Gess-Newsome, 2015)

2. Personal Pedagogical Content Knowledge and Skills (PCK&S): "***The act of*** teaching a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes (Reflection in Action, Tacit or Explicit)" (Gess-Newsome, 2015).

In this new model, student outcomes are included. Between classroom practices and student outcomes lie student amplifiers and filters. Similar to the teacher amplifiers and filters, student amplifiers and filters strengthen or narrow the effect of what occurs in the classroom on student outcomes. Student amplifiers and filters are contextual and can have great influence on student engagement in the classroom. They are such things as: "socioeconomic status, parental involvement, community expectations, student demographics, intelligence and working memory, background knowledge and misconceptions, motivation, self-regulation, ability to pay attention, persistence, health, nutrition, physical activity, and school attendance" (Gess-Newsome, 2015, p. 38). These factors can also amplify or filter the effects of instructional learning experiences. They can make it much more difficult to "trace the impact" of teaching and instruction in the classroom to student outcomes and measures (e.g. end of instructions or standardized tests).

Student outcomes are the final results of instruction, pedagogy, and preparation. The student outcomes provide feedback to the teacher and can serve as teacher amplifiers and filters themselves. If teachers are seeing successful student outcomes, then this serves to amplify TPK and TSPK. If a teacher is not seeing success in student outcomes, then this can serve to filter teacher beliefs about their TPK and TSPK. Likewise, successful student outcomes will amplify these components.

This model can be useful for targeting specific components of teaching related to PCK. It focuses on student outcomes and how they influence teachers' instructional beliefs and practices. With this new model, the specific types of PCK that will be needed for new modes of teaching can be studied and documented more accurately with the intention of describing effective science teaching practices. New reforms in science teaching call for three-dimensional learning and teaching (NRC, 2012; NGSS Lead States, 2013). These models can serve to measure and describe the types of PCK that will be required for successful three-dimensional learning and teaching.

These differing viewpoints about PCK can be seen in how PCK models have continued to grow and evolve becoming more refined and relevant to current teaching reforms and, in some ways, more complex. In all of these variations of PCK, the content knowledge a teacher possesses is only a part of the solution. A better understanding of PCK is needed for teachers to facilitate and successfully create opportunities for deep conceptual understanding for students requiring that teachers not only know their content but they must also possess skills and teaching strategies that match their intended educational goals (Kind, 2009). PCK represents this specific knowledge that teachers utilize in crafting and carrying out instruction within their classrooms (Kind, 2009).

Empirical PCK Research

The professional knowledge of teachers has been identified as essential for effective teaching (Abell, 2007; Kirschner et al., 2016). The ability to understand, measure, and represent the development of the pedagogical practices of science teachers could contribute to the ideas about effective and high-quality science teaching (Kind, 2009). There is an abundance of empirical research that has investigated PCK (Appleton, 2008; Ball, Thames, & Phelps, 2008; Bertram, 2014; Bertram & Loughran, 2012; de Jong, van Driel, & Verloop, 2005; Demirdöğen, 2016; Garritz, Labastida-Piña, Espinosa-Bueno, & Padilla, 2010; Hanuscin, Menon, & Lee, 2011; Hume, 2010; Jong & Valk, 2007; Juhler, 2016; Jüttner & Neuhaus, 2013; Kirschner et al., 2016; Loughran, Berry, & Mulhall, 2007; Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001; Loughran, Mulhall, & Berry, 2004; McNeill & Knight, 2013; Rowan et al., 2001; Tosunoglu & Lederman, 2016; Turner, 2011; van Driel, Verloop, & de Vos, 1998).

Some of this research sought to measure PCK in some form by focusing on the components of PCK and/or teacher action, reasoning, and planning (Jüttner & Neuhaus, 2013; Kirschner et al., 2016; Rowan et al., 2001; Tosunoglu & Lederman, 2016; Turner, 2011), while other research has sought to capture the essence of what constitutes PCK (Alvarado, Garritz, & Mellado, 2015; Appleton, 2008; Ball et al., 2008; Bertram, 2014; Bertram & Loughran, 2012; Chordnork & Yuenyong, 2014; Daehler, Heller, & Wong, 2015; de Jong et al., 2005; Demirdöğen, 2016; Garritz et al., 2010; Hanuscin et al., 2011; Hume, 2010; Jong & Valk, 2007; Juhler, 2016; Kirschner et al., 2016; Loughran et al., 2007; Loughran et al., 2001; Loughran et al., 2004; McNeill & Knight, 2013; Park & Suh, 2015; van Driel et al., 1998).

When looking at PCK research relevant to the study at hand, three main categories emerged: (a) PCK studies seeking to describe PCK within a specific context; (b) PCK studies seeking to validate new PCK data collection instruments; and (c) PCK studies utilizing Content Representation (CoRes) and Pedagogical and Professional Experience Repertoires (PaP-eRs). Each category will be discussed in more detail in the following sections starting with studies that were more general in nature (i.e. PCK descriptive studies) and moving to studies that sought to be very specific in how and what they were investigating in relation to PCK (i.e. PCK instrument validation studies) and finally discussing studies that utilized CoRes and PaP-eRs in their methodology.

Describing PCK.

van Driel, Verloop, and de Vos (1998) in the Netherlands used a case study approach to investigate how chemical education teachers translate subject matter knowledge into student understanding. These researchers looked specifically at the idea of teachers' craft knowledge, which encompasses prior knowledge along with continuing school learning experiences and building on teachers' background knowledge (van Driel et al., 1998). An experimental course on chemical equilibrium was created for students, and 12 in-service teachers experienced professional development centered around the concepts related to craft knowledge. Researchers analyzed audio recordings of the workshops and administered questionnaires to the teacher participants. The researchers found that when teachers experienced professional development focused on the explicit development of their PCK in the context of chemical equilibrium, they were better able to implement effective teaching strategies for instruction around chemical equilibrium.

Research conducted by Heller, Daehler, Shinohara, and Kaskowitz (2004) utilized a case study approach in which teachers engaged in six case-based discussions focusing on the instruction and content of electricity and electrical circuits. Following each discussion, the researcher would present each teacher a case and ask specific questions about what they would do in each scenario. The responses were then analyzed using a rubric designed to measure PCK specific to electricity and electrical circuits and instruction about these concepts. They found, that through this process, both teachers' content knowledge and PCK increased.

Another qualitative case study conducted by de Jong, van Driel, and Verloop (2005) investigated preservice teachers' PCK involving the use of particle models in chemistry education. This study carried out in the Netherlands, investigated the PCK of 12 preservice teachers, all possessed a master's degree in chemistry and enrolled in a post graduate teacher education program. This study sought to determine the PCK of pre-service teachers regarding the use of particle models, instructional strategies useful in teaching particle models, and how these teachers' PCK might change after participation in a course-module focused on the use of particle models. Utilizing a series of open-ended questions, the researchers found that pre-service teachers' PCK is mostly fragmented, but after the course-module intervention, the pre-service teachers were better able to identify learning difficulties related to the use of particle models in chemistry education.

Another PCK study performed by de Jong and van der Valk (2007) explored school-based in-service teacher professional development centered on the topic of water quality. This study took place in an in-service course focused on helping teachers guide students into open inquiry learning. Seven experienced teachers from two high schools participated in this course. During the intervention, five institutional meetings were held and three intentional lessons were implemented. Audio recordings of discussions held during these meetings were made, additionally observation notes were recorded, and teacher generated materials used in the classrooms were collected. It was found that, through participation in the in-service course, teachers were able to develop their PCK in several places. For example, teachers were more aware of students' learning as well as associated difficulties. Additionally, teachers were better able to effectively implement instructional strategies to scaffold students to deeper understanding by knowing when to give students space to think and express ideas and when to provide more direct support. They also found that PCK development progressed differently for each teacher. Several implications emerged that could be applied to teacher professional development programs: (a) acknowledge that teachers are professionals and as such provide strategies and materials as half-finished products so that teachers can apply their own PCK to adapt such resources; (b) create a collaborative community for teachers to engage in to become co-owners of new initiatives; (c) create opportunities for teacher to engage in cooperative learning with their colleagues; and (d) model and employ the strategies and resources that you plan for teachers to implement.

Beginning in 2007, a long-term NSF-funded project began to research PCK on a large scale (Daehler et al., 2015). In this study, 260 elementary teachers were randomly assigned to three different interventions and a fourth group served as a control. The interventions were structured as three, eight-hour sessions each focused on different teaching aspects such as hands-on investigations, sense-making discussions, and science readings. Teachers then completed open ended written responses to a survey. The researchers found that having teachers engage in analyzing case studies or analyzing student work improved PCK and that all three interventions increased student scores.

Appleton (2008) conducted a qualitative case study of elementary teachers' PCK development through a mentor program in Australia. This study followed two elementary teachers, both with at least 10 years of experience, through a two-day workshop and follow-up yearlong mentorship. The researcher constructed case descriptions using teacher narratives and observation field notes. Through the participation in the mentorship process and explicit reflection, growth occurred in the teachers' PCK in utilizing a constructivist framework to: (a) plan for and provide inquiry based hands-on experiences; (b) shift control to provide room for students to think for themselves resulting in deeper student understanding; (c) allow for flexibility when planning and carrying out student learning experiences; (d) facilitate students' metacognition regarding their own learning. This resulted in the participating teachers developing the ability to transfer these practices to disciplines beyond science in addition to having an improved self-confidence in their science teaching.

A long-term case study utilizing archived data from the National Study of Education in Undergraduate Science looked at the impact of undergraduate courses integrating science reforms on the PCK of elementary teachers (Turner, 2011). This study involved 35 faculty members and 91 in-service teachers from 103 higher education institutions who participated in the NASA Opportunity for Visionary Academics (NOVA) professional development. Through participation in reform based courses as undergraduate students, the elementary in-service teachers indicated that during their undergraduate science methods courses they learned science by actively engaging in the practices of science. This allowed the teachers to understand that science is a process, to utilize modeling and investigations to understand difficult concepts, to apply concepts to new situations, and to develop the ability to reflect on how they would plan to implement such learning approaches in their classrooms.

Another study centered on the development of teachers' PCK of scientific argumentation through professional development (McNeill & Knight, 2013). About 70 K-12 teachers in the New England area participated in a series of professional development workshops focused on the development and use of scientific argumentation in the classroom. Teacher assessments were administered pre/post workshop, video recordings were made of the workshops, and teacher artifacts were generated both during the PD and in preparation for classroom learning tasks. These data were independently coded and triangulated. They found that the PD supported teachers in developing a common understanding of scientific argumentation and helped teachers develop their PCK in relation to facilitating and understanding student conceptions of the structural components of scientific argumentation as evidenced in their science writing.

Using a case study approach, Demirdöğen (2016) looked at science teacher orientations and how teachers interacted with components of PCK in teacher practice. Eight preservice teachers engaged in a week-long lesson development training. Following this training, they completed an open-ended survey and completed semi-structured interviews. A constant comparative analysis was conducted and three main assertions were determined: (a) teachers' purpose directly determined the PCK components that were utilized, (b) teachers' belief about the nature of science did not influence a teacher's PCK unless there was explicit emphasis, and (c) teachers' beliefs about learning and instruction mainly interacted with choice of instructional strategies.

Additionally, it was found that when planning instruction for field experiences, pre-service teachers' did not typically apply the theory they learned with fidelity in their instructional practices.

Another study focusing on PCK in physics lesson development, utilized a simplified version of Magnussen's PCK model (see Figure 5) and looked at the introduction of a lesson study model on the evolution of lesson development by fourteen preservice teachers (Juhler, 2016). These lessons were then analyzed using deductive content analysis and coded into four main categories (knowledge of curriculum, knowledge of student understanding, knowledge of

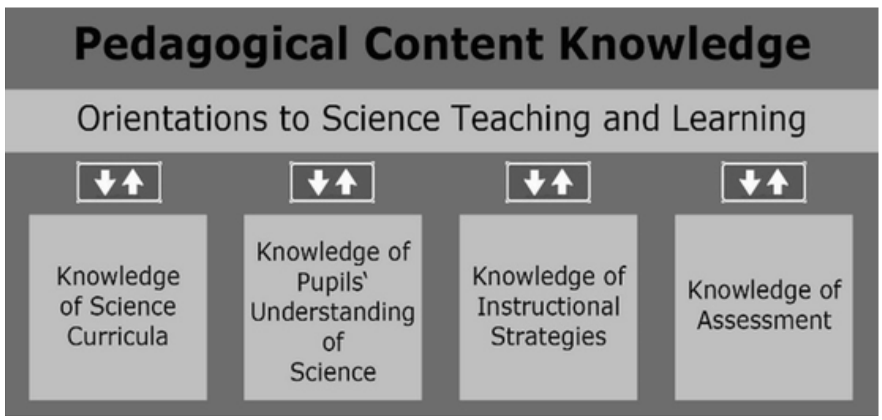


Figure 5. Simplified PCK Model. Reprinted from "The Use of Lesson Study Combined with Content Representation in the Planning of Physics Lessons During Field Practice to Develop Pedagogical Content Knowledge" by Juhler, M. V., 2016, *Journal of Science Teacher Education*, 27(5), p.537. Copyright 2016 by The Association for Science Teacher Education.

instructional strategies, and knowledge of assessment) and 16 more specific sub-categories. The researcher found that pre-service teachers in the intervention group who focused on curriculum and instructional strategies that were developing and implementing lessons in a normal, non-lesson study environment took a more holistic approach focusing on all four main categories thereby have a more well-rounded form of PCK.

Instrument development and validation. As many researchers have sought to capture and describe PCK in different circumstances, others have sought to construct and validate new instruments that might provide more nuanced information regarding PCK in specific areas. Each of the following studies in one way or another have captured PCK and have focused on niches within PCK research and its implication in learning and teaching in science and other non-science domains. They are described in more detail in the following section.

More recently, a study conducted in Germany and the United States explored PCK related to the teaching of biology (Jüttner & Neuhaus, 2013). This study took place within the larger context of the ProwiN (the German acronym for professional knowledge of science teachers) project, which focused on determining characteristics of PCK related to biology, chemistry, and physics. A small subset of this project, five teachers from Germany and six teachers from the United States, took part in this study. A mixed method study was employed, utilizing a quantitative pencil and paper test along with qualitative think aloud interviews. The instrument consisted of 24 items along three knowledge dimensions (declarative, procedural, and conditional knowledge), and three PCK specific components focusing more specifically on teachers' content knowledge. Researchers also used "think aloud" interviews to test the validity of the survey instrument and to further uncover teachers' PCK. Teachers responded in writing to a question, verbalizing their thinking as they answered. Following the written response with think aloud, the teacher responded verbally to additional question items. The researchers concluded that the use of think aloud interviews proved to be a successful strategy to measure the content validity of the PCK survey items and could be a method for constructing other PCK survey items.

More recently a study was presented at the 2016 National Association for Research in Science Teaching (NARST) Annual International Conference to evaluate the pedagogical content knowledge of socio-scientific issues or PCK-SSI (Tosunoglu & Lederman, 2016). In this study, four biology teachers completed a three-part, open-ended survey instrument, which examined teacher demographics, teachers understanding of SSI, and teachers' understanding of the teaching of SSI. The third part of the survey instrument was organized around six domains: pedagogy, curriculum, subject matter knowledge, knowledge of students, knowledge of school culture, and PCK. To accomplish measuring these characteristics, the teachers were instructed to select two of the four available scenarios and respond to corresponding six open-ended questions. The researchers were able to successfully identify some aspects of teachers' PCK related to SSI. It was determined that SSI should be integrated into the content knowledge in the science classroom. Through the use and refinement of this instrument, the researchers foresee the opportunity to be more explicit regarding SSI instruction in science education.

As a part of the ProwiN (Professional Knowledge in Science) project, another recent study led by Kirschner, Borowski, Fischer, Gess-Newsome, and von Aufschnaiter (2016), developed and validated an instrument to measure

PCK for physics teachers. The resulting instrument consisted of 17 open-ended questions and measured teachers content knowledge, pedagogical knowledge, and PCK. Kirschner et al. utilized a framework that blended content knowledge (CK) and pedagogical knowledge (PK) to form a teacher's PCK within the context of the domain of physics education (see Figure 6). In this model, domain refers to large scale disciplines such as physics, biology, or astronomy. Whereas, topics refer to the specific concepts within a particular domain. Each item on the instrument presented a scenario or a prompt related to physics instruction in the classroom, to which teachers responded to open-ended questions. The survey instrument was administered to 186 experienced physics teachers, 21 non-physics teachers, 79 pre-service physics teachers, and seven physicists. The instrument was found to be a valid method for measuring these qualities and could provide insight into PCK in physics classrooms. The

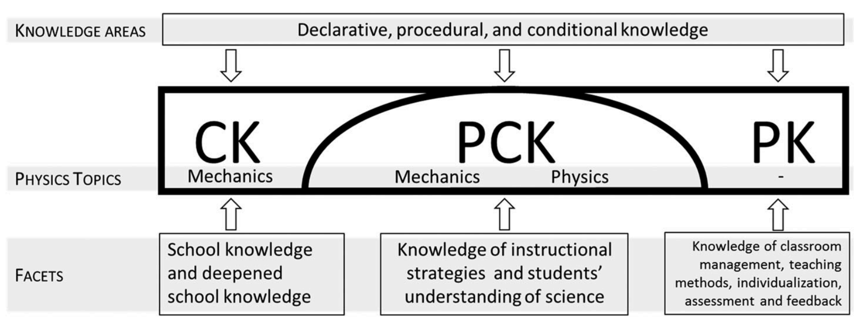


Figure 6. PCK in a Physics Context. Reprinted from "Developing and evaluating a paper-and-pencil test to assess components of physics teachers' pedagogical content knowledge" by Kirschner, S. Borowski, A., Fischer, H. E., Gess-Newsome, J. & von Aufschnaiter, C., 2016, *International Journal of Science Education*, 38(8), p.6. Copyright by Informa UK Limited, trading as Taylor and Francis Group.

researchers found a strong correlation between teachers PCK and their PK and their CK and PCK with smaller correlations between teachers' CK and PK. Each of the dimensions (PCK, CK, and PK) are distinct from each other; however, they are closely related to one another and each can influence the other dimensions. Where these studies sought to capture more detailed, close-range information about science teachers' PCK in a very specific context using very targeted study instruments, the following studies all utilized a common framework and similar instruments (i.e., Content Representations, also known as CoRes, and Pedagogical and Professional-experience Repertoires, PaP-eRs) to develop a deeper understanding of PCK in science education.

CoRes and PaP-eRs. Many researchers have attempted to capture PCK using a case study approach. However, a more formalized, systematic approach has been developed with the purpose of capturing PCK and representing it in a way that was accessible and useful for others in helping them to understand their own PCK and further develop it within a specific content area. In 2001, Loughran, Milroy, Berry, Gunstone, and Mulhall developed a method, called Content Representation, or CoRe. Like previous researchers, they attempted to capture PCK utilizing similar case study methods and found it was difficult for teachers to articulate the tacit nature of their practice (PCK). However, they found that cases are not able to portray the fullness of a teacher's PCK (Loughran et al., 2001). They concluded that, "to see PCK in the classroom, or in a teacher's articulation of their practice, is to see a mixture of interacting elements which, when combined, help to give insights into the PCK informing the practice" (p. 292).

In developing CoRes as a research strategy, the researchers identified important features that should be included in a representation of PCK including:

(a) classroom reality that shows the complexity of a real teaching situation including a diversity of students' responses; (b) teachers' thinking about the content and the responses from the students; (c) students' thinking showing the links they may or may not be making; and (d) the characteristics related to the content that shapes the learning and teaching experience and why. According to the researchers, a CoRe provides an overview of how teachers approach the teaching of the whole of a topic and the reasons for that approach – what is taught and how and why – in the form of propositions (Loughran et al., 2001; Loughran et al., 2004). Importantly, a CoRe refers to the teaching of a particular topic to a particular group of students (Loughran, Berry, & Mulhall, 2012). A CoRe (see Table 2) is composed of eight components, all organized under an identified "big science idea/concept". The eight components are expressed as questions or prompts for the teacher to respond.

Table 2

Sample CoRe Template

Big Science Ideas/Concepts	A	B	D	E
What you intend the students to learn about this idea/concept				
Why it is important for students to know this?				
What else you might know about this idea (that you don't want the students to know yet)				

Difficulties/limitations connected with teaching this idea	
Knowledge about students’ thinking that influences your teaching of this idea	
Other factors that influence your teaching of this idea	
Teaching procedures (and particular reasons for using these to engage with this idea	
Specific ways you will use to ascertain students’ understanding or confusion around the idea	

Note. Adapted from “Understanding and Developing Science Teachers’ Pedagogical Content Knowledge” by Loughran, J., Berry, A., & Mulhall, P., 2012 p. 22. Copyright 2012 by Sense Publishers.

The first prompt, what you intend the students to learn about this idea, serves as a starting point for teachers to begin to unpack the big idea. The second prompt shifts from what, to thinking about why it is important for students to know this, allowing the teachers to be explicit about the relevance of the idea to students’ lives. Thirdly, teachers are asked to reflect on what else they might know about the big idea that they do not intend for students to know yet. The fourth prompt asks teachers to identify possible difficulties or limitations connected with teaching the big idea. The next prompt, the fifth, allows teachers to be intentional about connecting the idea to student’s culture and prior ideas by having teachers describe their knowledge about students’ thinking that influences the teaching of the big idea to this group of students at this time.

Related to the fifth prompt, the sixth further explores the context in which the idea is being taught, i.e. what other factors influence your teaching of this idea. Prompt seven, teaching procedures and particular reasons for using these to engage with this idea, allows teachers to begin to connect their thinking in the previous prompts to the plans for classroom instruction. The final prompt, specific ways of ascertaining students' understanding or confusion around this idea, provides an opportunity for teachers to think about the possible ways that student thinking can be uncovered and evaluated. Utilizing a CoRe allows a teacher's PCK to become more visible by illuminating how a teacher articulates a particular topic providing a window into the instructional decisions teachers make when planning for learning experiences. As such, a CoRe can showcase the hidden links that a teacher makes between the content taught, the students in the classroom, and instructional practice (Loughran et al., 2004).

As useful as CoRes are for making teachers' PCK visible, they only show teachers' intended practice and their thoughts behind those intentions. To gain a more complete picture of PCK, one must also document how these plans are actually carried out in the classroom. In order to accomplish this task, the researchers built upon CoRes by creating an additional strategy, Pedagogical and Professional-experience Repertoire (PaP-eR). A PaP-eR is constructed around a specific content idea shedding light on how a teacher's pedagogy is shaped and should provide linkage between the observed practice and the explicit body of knowledge outlined in the related CoRe (Loughran et al., 2001; Loughran et al., 2004).

Specifically, PaP-eRs are narrative accounts that emerge from teachers' enactment of science instruction, written in such a way as to "elaborate and give insight into the interacting elements of the teacher's PCK" that makes this tacit knowledge accessible to others, facilitating reflection on their own practices and possibly prompting change in their own instructional practice. As Loughran et. al. (2012) explained, "PaP-eRs bring the CoRe to life and offer one way of capturing the holistic nature and complexity of PCK in ways that are not possible in the CoRe alone" (p. 19). Each PaP-eR is unique as it may be constructed from multiple perspectives (e.g., teacher, student, or outside observer) and can also take different forms depending on the facet of PCK being portrayed (e.g., descriptions of classroom observations, narrative of teacher interviews, callout boxes, or documentation of teacher out loud thinking). Both Cores and PaP-eRs can be combined into a "Resource Folio" and work together to provide a robust picture of teachers' PCK in a specific learning context with specific students (Loughran et al., 2012).

Utilizing the process of teachers examining and using Resource Folios consisting of CoRes and PaP-eRs as an intervention, Loughran, Berry, and Mulhall (2007) investigated science teachers' PCK around inquiry learning. During the course of this three-year longitudinal study, a total of 50 high school science teachers placed in two groups participated. Researchers conducted 24 pre/post interviews, 12 classroom observations, and 10 pre/post small group discussion interviews. During the pre-CoRe and PaP-eRs intervention, two major themes emerged regarding teacher PCK related to inquiry. The first theme was centered around the act of science teaching including the following subthemes: activities that work, content familiarity, and student engagement. The second theme, linking learning and teaching, gave the notion that a connection exists between teachers' understanding of content and their ability to engage students in meaningful learning in that content. Under the second theme the following subthemes emerged: relevance to students' real world, sense of progression in learning, organization, and teaching repertoire.

After the participants interacted with CoRes and PaP-eRs, their discussions and interviews were again coded and analyzed for possible themes. Two main themes emerged post intervention, planning for instruction (i.e., planning/structure matter, content organization, and content interaction) and re-conceptualizing practice through professional learning (i.e., knowing the what and why of teaching, awareness of student perceptions, and reflection on what happens in the classroom). Teachers found the use of CoRes and PaP-eRs helpful for facilitating their professional growth and the researchers found that their use was effective in capturing and portraying teachers' PCK. One participating teacher stated, "Knowing content is extremely important, but knowing how to teach the content to particular students is also extremely important. It is necessary for me to have a large repertoire of various ideas so that students learn and understand the content" (Loughran et al., 2007, p 100.). This shows the teacher's awareness of their own practice and their conscious perceptions about the interaction of content knowledge (CK), pedagogical knowledge (PK), and contextual knowledge, which are major components forming the amalgam of PCK (Gess-Newsome, 1999; Otto & Everett, 2013; Pringle, Dawson, & Ritzhaupt, 2015).

A study conducted in Mexico used a modified version of Content Representation, Inquiry Content Representation (I-CoRe) to gain insight into teachers' PCK in relation to inquiry based teaching or Pedagogical Inquiry/Content Knowledge (PICK) (Garritz et al., 2010). Five high school teachers with experience in inquiry teaching examined a set of seven inquiry activities which constituted the big ideas for the teachers' I-CoRes. The I-CoRes and follow up interviews were used to create PaP-eRs to facilitate the capturing of teachers PICK. Using PCK as a framework, the researchers were able to discover that nearly all of the teachers in the study had used, to some degree, inquiry based practices, such as question posing, to develop their students' ability to think like a scientist.

Through the QUEST program, Quality Elementary Science Teaching, three graduate students and a mentor took part in a self-study relying on reflective practice, action research, and practitioner research (Hanuscin et al., 2011). Three science teachers enrolled in a graduate program, took part in a state funded professional development program, participated in a two-week summer institute focusing on the content of light and the 5E learning cycle (Bybee, 2013) that included follow up through the next academic year. A resource folio, utilizing a modified CoRe was constructed and analyzed for each participant. Two main findings of the study highlighted that having an experienced other, a mentor, during the process of a self-study showed that the expert's view differed from the novice and that when a mentor used prompting questions it could help the mentee make the unknown explicit. Additionally, the process of self-study provided a meaningful strategy in which novice teachers were able to identify gaps within their own PCK (Hanuscin et al., 2011).

A meta-analysis of current PCK research determined the general characteristics of PCK studies and summarized the possible implications of this PCK research (Aydin & Boz, 2012). These conclusions maintained their relevance to the field of PCK research as it currently exists. The majority of the PCK research was qualitative in nature and most studies sought to describe the relationship between the components of PCK in specific contexts (e.g. chemistry, physics, biology) and how teachers' PCK could be developed within the given context. Most of the studies described in this review specifically focused on secondary education (n=19) and studies investigating PCK in pre-service teachers versus in-service teachers were somewhat equally represented. Through reviewing this research, it had been determined that both pre-service and in-service teachers often do not have adequate content knowledge to have robust PCK. This would mean that an intervention designed to increase a teacher's PCK would be more successful if set within the context of a specific science domain. Most teachers do not think in terms of PCK or explicitly reflect on their practice as completely as the utilization of PCK would allow. When looking at the individual components of PCK, most participants preferred or utilized traditional teaching methods and had difficulty applying different instructional methods and strategies. To successfully develop PCK, this idea would have to be explicitly planned and addressed. Additionally, in-service teachers benefited greatly from in-service professional development focused on increasing the development of one or more components of a teachers' PCK (Aydin & Boz, 2012). Without training that explicitly sought to provide time and explicit instruction and reflection about one's own teaching practices and knowledge as related to the components of PCK, teachers were not able to further develop their own PCK in meaningful ways (Aydin & Boz, 2012).

Other more recent studies conducted in Thailand (Chordnork & Yuenyong, 2014), Australia (Bertram, 2014), and Mexico (Alvarado et al., 2015) investigated the development of teachers' PCK in relation to different science concepts. Each of these studies utilized CoRes and PaP-eRs as a means to capture and describe the growth of teachers' PCK. Each of these studies were able to determine that the use of CoRes and PaP-eRs can be an effective strategy to uncover and describe teachers' PCK, and, that by using them as a reflective tool for teachers, they can facilitate the personal growth of individual teachers' PCK. Using CoRes and PaP-eRs, teachers were better able to focus on explicitly preparing for meaningful instruction and as a result they were able to improve aspects of their teaching practice (Chordnork & Yuenyong, 2014). Each teacher participant was able to gain more insight into their own teaching practices and beliefs.

PCK Research Summary

Each of these studies described the nuances related to PCK research and how rich the field of PCK research has evolved. There is still much work to be done to uncover more of the facets of science teachers' PCK. This is especially true as science teachers continue to modify and refine their craft as new reforms take place in science education. These studies into PCK have focused on different aspects of PCK and how PCK influenced education in the classroom. Pedagogy, subject matter, and field practices were not always carried out in an integrated manner. According to Shulman, "Just knowing the content well was really important, just knowing general pedagogy was really important and yet when you added the two together, you didn't get the teacher" (as quoted in Berry, Loughran, & van Driel, 2008, p. 1275). Knowing how to accurately describe and measure developing PCK can help improve teacher instruction in both in-service teachers and preservice teacher preparation especially in relation to new science reforms where these ideas have not yet been explored and described.

Conflicts within PCK research. With all of the research about PCK, there are conflicts that have risen (Friedrichsen et al., 2011). Many times, some research referred to the teaching orientation in different ways or used different teacher orientations than as outlined in the main PCK model (Friedrichsen et al., 2011; Gess-Newsome, 1999). Additionally, sometimes the relationship between various PCK components and/or the PCK components and teacher orientations have been described ambiguously and the connections have not been clear (Gess-Newsome, 2015). Other studies have completely ignored the role of teaching orientation or categorized teachers as having only one single orientation when assessing or describing developing PCK (Friedrichsen et al., 2011). These conflicts can result in confusion or vagueness when describing and researching PCK.

Each model used to represent and describe PCK has variations that can make it difficult to unify the ideas of PCK (Gess-Newsome, 2015; Shulman, 2015). For example, a recent report on science teacher learning (NASEM, 2015) identified three areas in which science teachers will need to further develop their understanding:

- "the knowledge, capacity, and skill required to support a diverse range of students;"
- "content knowledge, including understanding of disciplinary core ideas, crosscutting concepts, and scientific and engineering practices; and"
- "**pedagogical content knowledge for teaching science**, including a repertoire of teaching practices that support students in rigorous and consequential science teaching." (p. 109)

This perspective places an understanding of the three dimensions of science under the domain of content knowledge and not explicitly under pedagogical content knowledge. Following this understanding, knowledge related to the three dimensions is distinguished separately from or as a possible component of pedagogical content knowledge. The most recent model of PCK (Gess-Newsome, 2015) looks much different than the model cited by most research

(Magnusson et al., 1999). Both are based on Shulman's original definitions of PCK (1986), but each model is nuanced in different ways. In order to overcome these conflicts, clear definitions and meanings of PCK, orientations, and PCK components will need to be outlined in future studies so to ensure that understanding is communicated effectively.

PCK in the Next Generation of Science Education

Even as teachers begin implementing 3D Learning and Teaching there are challenges that have and will arise as teachers move forward in this endeavor (Reiser, 2013). Changing the culture of science education takes much individual and collective time and effort, and changing one's educational beliefs and practices can be difficult. To change teaching practices requires an examination and reflection of beliefs about how people learn and why we do what we do in the classroom. This could prove to be a paradigm shift for many science teachers. Most teachers currently practicing in the field of science education would say their teaching beliefs align to constructivist worldviews (Banilower et al., 2013; Trygstad, Smith, Banilower, & Nelson, 2013). However, many who say that they use inquiry-based constructivist instructional practices still operate from a more traditional viewpoint and have an incomplete view of inquiry (Capps & Crawford, 2013).

With shifts to the new modes of teaching needed to successfully integrate 3D Learning and Teaching in the classroom, new forms of PCK will be needed that are specific to the context of 3D instruction. There is a specific body of knowledge associated with the three dimensions of NGSS and understanding and knowing why and how to implement the SEPs, CCCs, and DCIs in instruction are all necessary elements of any competent science teacher (Osborne, 2014).

Teachers who are skillful in their craft recognize and comprehend the complex practice of teaching and are capable of transforming knowledge into usable forms for students (Juhler, 2016; Nilsson, 2008). In order for teachers to be effective in transitioning to 3D Learning and Teaching that utilizes phenomena to drive instruction, new PCK should include "the science and engineering practices used to generate knowledge, the disciplinary core ideas, and the recognition of cross-cutting concepts" (Gess-Newsome, 2015 p. 32). This means that teachers will need to develop PCK and TSPK that is specific to 3D Learning and Teaching. This new framework could be a useful tool for teachers transitioning to 3D Learning and could be introduced and described by the researcher as Three-dimensional Pedagogical Content Knowledge (3D-PCK). Not only will teachers need to understand each individual dimension, SEPs, CCCs, and DCIs, of the *NGSS* (NGSS Lead States, 2013), but they will also need to understand how these dimensions work together and can be integrated seamlessly so that students are actively utilizing all three dimensions to make meaning and construct explanations (Allen & Penuel, 2015; Bybee, 2013; Moulding et al., 2015; Reiser, 2013). This new form of PCK would look different from PCK found in traditional science classrooms and would have characteristics directly related to 3D Learning and Teaching.

Gap in research: PCK in a phenomena-driven three-dimensional learning context. There is no system in place that captures data regarding the trends that are developing in science education as new reforms are being implemented (NASEM, 2015). Teachers will need support as they make these instructional shifts (NRC, 2012; Reiser, 2013). These supports can take the form of professional development, 3D integrated curriculum, teacher professional learning communities (Printy & Marks, 2004) focused on 3D Learning, and other unique forms of support centered on 3D Learning in the classroom. Each of these supports can provide interesting opportunities to document, describe, and measure how 3D-PCK is developing in teachers.

In referring to PCK research, Kind (2009, p. 2.) utilized Thomas Kuhn to describe the current field of PCK research, "Despite having occupied significant research time for over twenty years, it is not ready for wider dissemination". The ability of researchers and those supporting teachers to describe these special forms of PCK unique to 3D Learning could serve as the bridge for PCK research to move strictly from the realm of the academic and education policy to the practical world of the classroom. Thus, 3D-PCK is the focus of this current study. Currently, there no specific ways are documented to know how teachers are encouraged to engage in the development of PCK especially as related to 3D Learning (NASEM, 2015).

Proposed 3D PCK study model. While research into the implementation of 3D Learning is starting to be conducted (Hayes, Lee, DiStefano, O'Connor, & Seitz, 2016), no common framework for teachers, researchers, and others in the field of science education exists for describing 3D-PCK (NASEM, 2015). Building on prior conceptual frameworks (Gess-Newsome, 1999; Otto & Everett, 2013; Pringle et al., 2015), this current research study suggests a possible framework describing 3D-PCK (see Figure 7) to unify research and practice regarding phenomena-driven three-dimensional learning and teaching (3D Learning) and pedagogical content knowledge (PCK). In the proposed framework for this current study centered on 3D-PCK, Content Knowledge (CK) would represent knowledge of the three dimensions (SEPs, CCCs, and DCIs), especially someone who possesses strong science knowledge in a specific area (e.g., physics, biology, or engineering). Pedagogical Knowledge (PK) would include teaching strategies needed for successful teaching in the context of a science classroom. Contextual Knowledge (CxK) would focus on student equity (NRC, 2012) and could include knowledge of the specific classroom and the culture of the students present in a classroom (e.g., ethnic background, community, socioeconomic status, etc.).

Intersection A represents a teacher with strong knowledge in a content area (CK) and knowledge of effective teaching strategies (PK), but may not be able to connect these to real life experiences of their students (CxK). Intersection B represents a teacher with deep understanding of content area (CK) and understanding of students in their classroom (CxK), but lacks pedagogical skills and strategies (PK) to make connections between both.

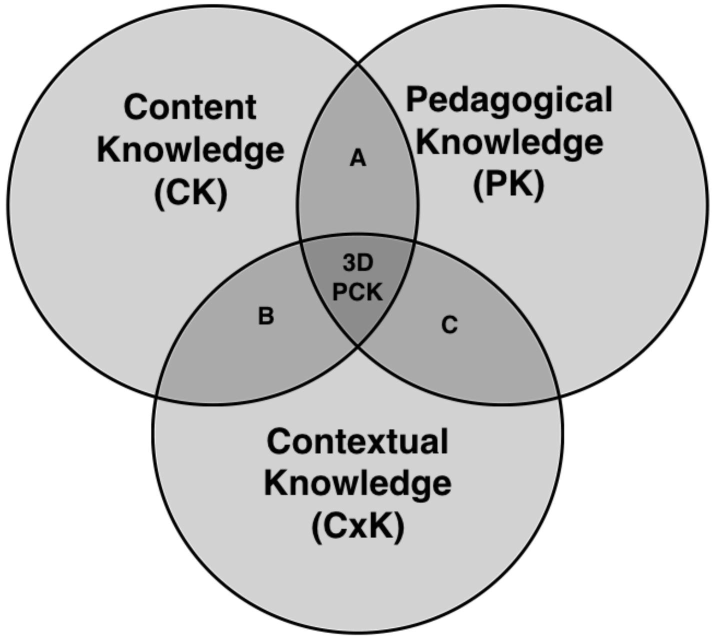


Figure 7. Proposed 3D-PCK framework.

Intersection C represents a teacher with good understanding of students and their backgrounds (CxK) with knowledge of good teaching strategies (PK) but lacks content knowledge (CK) that would help guide their students in constructing meaningful scientific understanding. As in this current study, this proposed 3D-PCK model could be the central framework to guide researchers to place 3D-PCK in a more accessible and usable place for teachers in the classroom as they endeavor to transition to 3D Learning and Teaching.

Hypothesis. The purpose of this study was to capture and describe the characteristics of teachers' PCK in a three-dimensional context in which grades 3 through 12 rural science teachers were working toward transitioning to this new type of learning. Both the central purpose of this study and the proposed framework were referenced when making decisions regarding data collection and also were utilized to address the selected research questions:

1. What are the characteristics of teachers identified with significant growth in understanding of 3-Dimensional Learning?
2. What are the characteristics of teachers identified with significant growth in the implementation of 3-Dimensional Learning?
3. How does teachers' 3D-PCK translate into their classroom instructional practices?
4. What experiences within the first year of a three-year 3D Learning focused professional development context can lead to growth in teachers' understanding and implementation of 3D Learning and Teaching?
5. What perceived outcomes resulted from participation in a 3D Learning-focused professional development program?

I hypothesized that third grade through high school science teachers who participated in a professional development program focused explicitly on 3D Learning and Teaching would increase their capacity for understanding, creating, and implementing 3D strategies, instructional tasks, and learning experiences for their students.

Assumptions. Within the scope of this study, it was assumed that the in-service teachers were capable of articulating their reasons for their instructional decisions related to 3D Learning. Additionally, it was assumed that participants in this study would have participated in the larger project focused on assisting teachers in the transition to 3D Learning. As such, it was expected that each teacher was actively seeking to implement 3D Learning strategies and teaching philosophies into their classroom practice. It was also assumed that because of their participation in the larger project, each teacher taking part in this study had written and implemented at least one phenomena-driven three-dimensional instructional task in their classroom with their students. It was this experience that provided the opportunity for reflection for the participants of this study.

Summary

A robust background of PCK knowledge existed to guide this research. PCK as a research field has a rich research history and has shown to be flexible to new contexts. The construct of PCK is able to adapt to in order to describe teaching even as new reforms, beliefs and practices develop. However, few studies have been conducted regarding PCK in a 3D context. This gap in the research presented a great opportunity to contribute to the field of both PCK research and the research and practice regarding phenomena-driven three-dimensional learning. 3D-PCK as described in this study and in future studies could be a valuable framework for teachers, curriculum coordinators and developers, school administrators, PD providers, and teacher preparation programs as they continue to implement and support phenomena-driven three-dimensional learning and teaching in classrooms.

This chapter focused on many key issues relevant to the study of PCK in both pre-service and in-service education programs including an overview of what entails PCK, the models used to represent PCK, recent case studies investigating PCK, studies validating new PCK instruments, the extensive use of CoRes and PaP-eRs to document PCK, and the lack of PCK research in the era of NGSS of 3D Learning. The study of PCK is a vibrant field with opportunity for application in both the world of academic research and the practical world of the science classroom. This current study sought to be a bridge between these two worlds.

Pedagogical Content Knowledge (PCK), the tacit hidden knowledge behind the instructional decisions teachers make, lies at the intersection of a teacher's pedagogical knowledge (knowledge of instructional methods and strategies), content knowledge (knowledge of subject matter, in 3D Learning knowledge of SEPs, CCCs, and DCIs), and contextual knowledge (knowledge of students' culture and prior conceptions) (Shulman, 2015). Researchers have sought to capture different facets of PCK in different contexts. Most researchers have found that when PCK has been used as a framework or for explicit reflection or planning that most teachers are capable of increasing at least components of their PCK (content knowledge, pedagogical knowledge, or contextual knowledge) if not their PCK as a whole. Still, as teachers transition to 3D Learning in their classrooms, nominal research has been done into the types of PCK that teachers might need for this new type of learning and teaching.

Chapter 3: Research Methodology

Introduction

New reforms in science education require that teachers transition to new modes of thinking about instruction and learning. Both *A Framework for K-12 Science Education* (NRC, 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013) emphasize student learning by engaging in the practices of science and engineering while utilizing crosscutting concepts and disciplinary core ideas to construct explanations for natural phenomena. In order to accomplish this, science teachers will need to develop new forms of pedagogical content knowledge (PCK) which would be described much differently than PCK seen in traditional science classrooms. These new forms of PCK would explicitly acknowledge three-dimensional teaching and thinking and should describe the characteristics of learning, teaching ,and thinking associated with 3D Learning. This new form of PCK could be known as three-dimensional pedagogical content knowledge (3D-PCK).

To describe what 3D-PCK could be, I utilized the following research questions to guide this study:

1. What are the characteristics of teachers identified with significant growth in understanding of 3-Dimensional Learning?
2. What are the characteristics of teachers identified with significant growth in the implementation of 3-Dimensional Learning?
3. How does teachers' 3D-PCK translate into their classroom instructional practices?

4. What experiences within the first year of a three-year 3D Learning-focused professional development context can lead to growth in teachers' understanding and implementation of 3D Learning and Teaching?
5. What perceived outcomes resulted from participation in a 3D Learning-focused professional development program?

In relation to RQ1 and RQ2, I operationally defined teachers' characteristics as related to the descriptive data collected during Year One (Y1) of the project (i.e., grade level, years of teaching experience, years of science teaching experience, prior experience with student-centered aligned professional development, and prior experience with 3D-focused professional development). My hope is that this research and the subsequent findings can provide information that can be used as resources to support science teachers as they transition to these new modes of thinking about science instruction. This could serve to guide instructional decisions and influence science education at all levels.

Research Methods

I followed a mixed methods explanatory sequential design (Creswell, 2013; Creswell & Clark, 2018) to develop and carry out this two-phased study. Phase One included quantitative data collection and analysis and Phase Two included qualitative data collection and analysis. The nature of this study and the data sources precluded a purely quantitative study. An explanatory mixed methods design begins with quantitative data collection (e.g. Likert scale perception, belief, and attitudes surveys, self-report levels of use survey) and appropriate quantitative data analysis. These results informed the type and forms of qualitative data that were collected, including the possible instruments and protocol and/or the case to be studied, such as, which participants were selected (Creswell & Clark, 2018; Stake, 1995). After this step, qualitative data were collected (e.g., interviews, and analysis of teacher artifacts) and analyzed using appropriate analysis methods. Once the qualitative analysis was completed, I interpreted all of the data together to see what meaning emerged from the study (Creswell, 2013; Creswell & Clark, 2018).

To be more specific, I used the quantitative data analysis results to inform not only the type and form of qualitative data that were collected, but to also guide the case selection comprised of the participants who participated in semi-structured follow-up interviews. For Phase Two of the study, the qualitative phase, I used an instrumental case study approach (Baxter & Jack, 2008; Stake, 1995) to guide the collection and analysis of the qualitative data. A case study approach studies a phenomenon in its natural setting (Yin, 2010). Case study as the name implies is the investigation of a single case in that it is a bounded system (e.g. it has a clear beginning and end, involves a defined group of individuals or even a single individual, and/or a specific setting) (Merriam, 2009). This case focused on a small subset (n=~3-6) of teachers participating in the first year of a three-year professional development program serving approximately 70 rural third grade through high school science teachers.

Setting and Participants

This study took place in the context of a three-year project funded through a federal Mathematics and Science Partnership (MSP) grant focused on providing professional development for teachers about phenomena-driven three-dimensional learning and teaching. This project involved a partnership between 16 rural school districts located in five rural counties ranging in size from 352 students to 2,860 students, in a state in the southwest region of the United States of America along with scientists, engineers, and science curriculum and pedagogy experts from a major university in the same state.

Permission was obtained through the Institutional Review Board (IRB) to conduct this study (see Appendix A). Any requirements requested by the IRB were met and planned for during the implementation of the study research methodology. A total of 67 teachers, spanning from third grade to high school physical science and biology participated in the CORPS project. In March 2016 administrators and science teachers from the partnering school districts were sent recruitment flyers and information about the CORPS MSP, and the 67 participating teachers self-selected into the project, of which 59 were female and 8 were male. The majority of the participants, 42, were elementary, 17 were secondary, teaching middle and high school, and 8 taught science at both the elementary and secondary level. The grade levels represented by these teachers are communicated in Table 3.

The anonymity of the participants in any published findings in journal articles was maintained. All teacher identifiers were removed from data. When referring to teachers or groups of teachers in the study; names, schools, and districts were anonymous pseudonyms and general. Even with these measures the researcher was careful when describing data and participants. The project served a specific group of teachers in a small set of school districts in Oklahoma. There may still be the possibility that any individual reading the journal article could infer the identity of a school and/or participant. Utmost care was taken so that the possibility of this was reduced as much as possible.

Table 3

Grade Level Coverage by Participating Teachers

Grade Level	Number of Teachers
3rd	13
4th	17
5th	15
6th	6
7th	10
8th	8
9th	9
10	9
11th	9
12th	2

When looking at the specific subjects that were taught by teachers at the high school level, most taught biology, followed by physical science, environmental science, chemistry, physics, and other science subjects (see Table 4). These teachers served 1,709 elementary students, 1,802 middle school students, and 1,003 high school students for a total of 4,514 students from grade 3 through high school physical science/biology.

Table 4

Subjects Taught by Participating High School Teachers

High School Subjects Taught	Number of Teachers
Biology	11
Physical Science	8
Environmental Science	6
Chemistry	4
Physics	3
General Science	5
Zoology	4
Anatomy/Physiology	4
Life Science	2
Earth and Space Science	2
Forensics	1

The ethnicity of the participants was comprised of Caucasian (n=61), American Indian/Native Alaskan (n=5), and multi-ethnic (n=1). Among the participating teachers, 54 held a bachelor's degree, 12 had a master's degree, and one had a Doctorate. Among the participants there was an average of 13.6 years of experience teaching and 11.9 years of experience teaching science specifically. Out of the 67 teachers who started with the project, 52 completed the first year of the project. The teachers selected to participate in this research study were selected from the 52 teachers that participated in the project from beginning to end.

The participants represented 16 school districts all meeting the Oklahoma State Department criteria for high need school districts:

- at least **40 percent** of the children were from families with incomes below the poverty line based on the Free and Reduced Lunch Count; OR
- had 20 percent poverty determined by the census; OR
- had been designated Priority or Focus School for the 2014 school year as determined by the state department of education; OR
- had any science classes not taught by highly qualified teachers. (All teachers providing direct instruction in science, including special education teachers, need to meet the highly qualified requirements of the No Child Left Behind Act.).

Intervention

The Central Oklahoma Rural Partnership for Science (CORPS) was designed utilizing professional development model recommendations from Loucks-Horsley, Stiles, Mundry, and Hewson (2009) to facilitate transformative learning experiences for teachers by providing time and structure for teacher learning; immersing them in learning aligned to 3D standards, content, and research; providing collaborative learning opportunities with colleagues and experts; and involving teachers in the alignment and implementation of phenomenon-driven three-dimensional curricula and assessments. The overarching goal of this project was to improve teacher content knowledge, pedagogical knowledge, and pedagogical content knowledge by increasing capacity to create and implement research-based, phenomena-driven three-dimensional instructional tasks, strategies, and diagnostic assessments.

Scaffolding was intentionally used to help participating teachers successfully create and implement instructional tasks which purposely and seamlessly integrate all three dimensions of the new science standards (science and engineering practices, crosscutting concepts, and disciplinary core ideas) throughout the task while utilizing aligned phenomena to drive learning throughout the task (Borko, Jacobs, & Koellner, 2010; Desimone & Garet, 2016; Reiser, 2013). This scaffolding of teachers' understanding of phenomena-driven three-dimensional learning occurred over the course of the project. This research focused on the first year of the CORPS project. During Year 1 of the project, teachers participated in a five-day summer institute (June 2016), a two-day collaboration session (July and August 2016), three follow-up Saturday workshops (September 2016; January and April 2017), two optional workdays (October 2016), and year-long onsite support including instructional task collaboration and lesson study observations with structured debriefs (Borko et al., 2010; Desimone & Garet, 2016; Lewis, Perry, & Murata, 2006; Reiser, 2013).

The first session of the project occurred during the Summer of 2016. Teachers attended a summer institute spending five, seven-hour days at the training. During this summer session, teachers were given the opportunity to experience phenomena-driven three-dimensional learning from the perspective of the student. In addition to modeling phenomenon-driven three-dimensional learning and teaching, PD facilitators familiarized teachers with the structure and components of the three dimensions of the standards and the foundation for these standards, *A Framework for K-12 Science Education* (NRC, 2012). Teachers explored each dimension (SEPs, CCCs, and DCIs) in depth to better understand what each of these components encompass, how these dimensions progress from K through 12th grade, how they should be integrated together, and what are phenomena and how they should be used within this type of instruction. Teachers were introduced to a proposed model for facilitating this type of learning (see Figure 8).

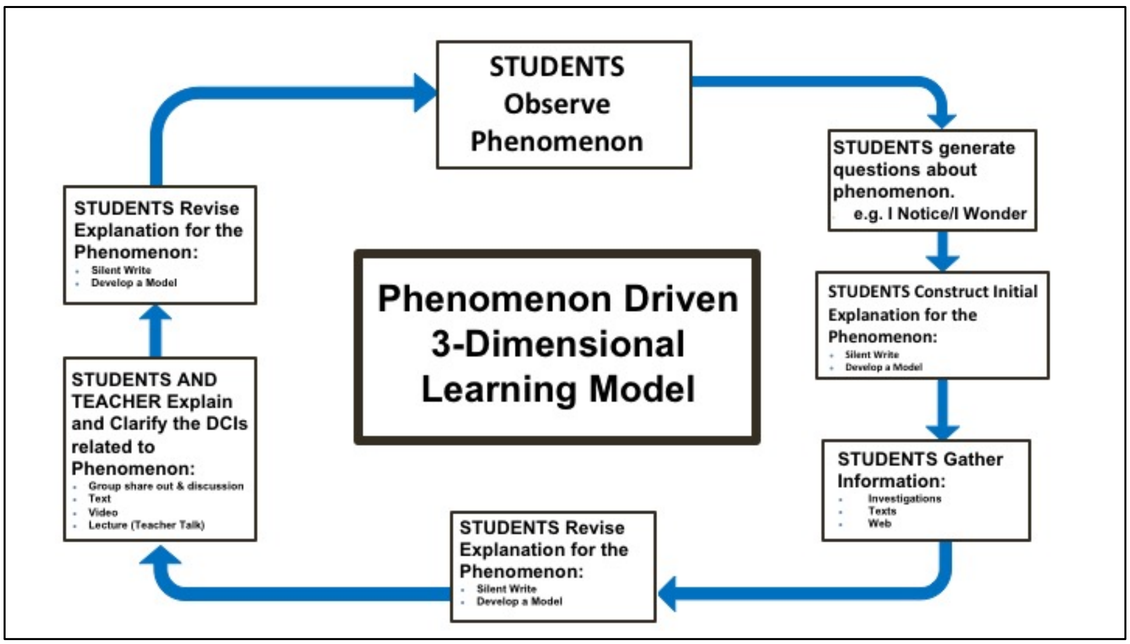


Figure 8. Possible Phenomena Driven Three-Dimensional Learning Model

Following the summer institute, teachers participated in two-day collaboration sessions organized by grade bands (grades 3-4, 5-6, 7-8, and high school physical science/biology). The purpose of these sessions was to have teachers begin to practice developing their own phenomena-driven three-dimensional instructional tasks specific to their grade level. To support teachers in developing these 3D instructional tasks, PD facilitators provided teachers an initial version of the instructional task template. This template served as a tool to facilitate teacher thinking about possible phenomena and each dimension of the science standards and the role they would play in the task. Over the course of the remaining Saturday sessions, this instructional task template would be streamlined by removing some of the scaffolding questions and reminders as teachers began to internalize the thinking needed to effectively develop, recognize, and implement phenomena-driven three-dimensional learning experiences in their own classrooms. During the academic school year, teachers implemented their 3D instructional tasks in their classrooms and debriefed and revised their phenomenon-driven three-dimensional instructional tasks through a modified lesson study (Lewis et al., 2006) in which the teachers, in grade level pairs, observed each other teach their instructional task, debriefed the lesson, and if possible reteach the lesson and conduct a third debrief for each lesson (see Appendix B). Over the course of the academic year, the project teachers participated in a total of 91 hours of professional development.

Data Collection and Analysis

The data collected for this study were only part of the data collected for the larger project within which this study is situated, to that effect only certain data instruments and items relevant to this study and 3D Learning were selected from the data that were collected during the overall project. Using an explanatory sequential design (Creswell, 2013; Creswell & Clark, 2018), data collection for this study was completed in two phases; quantitative data collection occurred first and the results from this data collection and analysis were used to select the teachers that participated in the second phase, qualitative data collection. Phase One was designed to answer my first two research questions:

RQ1. What are the characteristics of teachers identified with significant growth in understanding of 3-Dimensional Learning?

RQ2. What are the characteristics of teachers identified with significant growth in the implementation of 3-Dimensional Learning?

During Phase One of this study, select quantitative data collection occurred through both:

a) 3D Learning perception survey items measuring teacher perception of understanding of and comfort level with 3D Learning through Likert scale survey questions found in project needs assessment (see Appendix C) and teacher perception surveys (see Appendix D), and
b) self-reported data from the Concerns-Based Adoption Model (CBAM) Levels of Use survey (George, Hall, Stiegelbauer, & Litke, 2008 (see Appendix E).

The data related to teachers' perception of understanding of and comfort level with 3D Learning components and 3D Learning as a whole were analyzed to address RQ1. To address RQ2, the self-reported data from the Concerns-Based Adoption Model (CBAM) Levels of Use Survey (George, Hall, Stiegelbauer, & Litke, 2008) were anlyzed in relation to teachers' level of implementation of each component of 3D Learning and 3D Learning as a whole. Phase Two of this study focused on a select subset of the project participants and was designed to expand an understanding of the results from Phase One and ultimately provided data to answer my additional research questions:

RQ3. How does teachers’ 3D-PCK translate into their classroom instructional practices?

RQ4. What experiences within a three-year 3D Learning focused professional development context can lead to growth in teachers’ understanding and implementation of 3D Learning and Teaching?

RQ5. What perceived outcomes resulted from participation in a 3D Learning-focused professional development program?

Phase Two of this study utilized qualitative data from the selected subset of project participants (n=6). The qualitative data that were collected during the first stage of Phase Two addressed RQ3 included:

a) phenomena-driven three-dimensional instructional task artifacts constructed by teachers during Year 1 of the project (see Appendices F-I), and
b) Content Representations (CoRes) (Bertram & Loughran, 2012; Loughran et al., 2012; Loughran et al., 2001; Loughran et al., 2004) constructed post Year 1 from the teacher-constructed phenomena-driven three-dimensional instructional task artifacts and interviews, and
c) Pedagogical and Professional-experience Repertoires (PaP-eRs) (Bertram & Loughran, 2012; Loughran et al., 2012; Loughran et al.,

2001; Loughran et al., 2004) constructed from Year 1 teacher-modified lesson study observations, debrief notes, and post Year 1 interviews focused on the implementation of the teacher-constructed phenomena-driven three-dimensional instructional task (Lewis et al., 2006).

The qualitative data collected during the final stage of Phase Two that addressed RQ4 included:

a) semi-structured follow-up interviews focused on participant experiences during Year 1 of the project (see Appendix K).

Phase One Overview. Quantitative data were collected at various times during the course of the project (see Table 5). At the beginning of the project the teachers completed a needs assessment and a teacher perception survey both which contained items related to 3D Learning along with the CBAM Levels of Use survey. Teachers completed the teacher perception survey and CBAM Levels of Use Survey post summer institute, after the Saturday workshops, and

Table 5

Quantitative Data Collection Timeline

Date	Instrument Administration
June 23, 2016	Needs assessment Teacher perception survey CBAM
June 29, 2016	Teacher perception survey CBAM
September 24, 2016	Teacher perception survey
January 28, 2017	Teacher perception survey CBAM

post Year 1 activities. These data and associated instruments are discussed in more detail in the following sections.

3D Learning perception survey items. Select items from project data collection instruments (Teacher Needs Assessment Survey and Teacher Perception Survey) were utilized in the first phase of this study and will be later described in this section. The Teacher Needs Assessment Survey (see Appendix C) was administered prior to any professional development and consisted of three Likert-scale questions and three open-ended response questions. These questions focused on the participants' experience-level with the new 3D standards, their current understanding level with the SEPs, CCCs, DCIs, and performance expectations, confidence level in implementing 3D Learning, their understanding of the difference between former science standards and the new science standards, and what training and information they feel would be helpful for them in the process of transitioning to new 3D standards. The participants completed this survey using the Qualtrics online survey tool on Day 1 of the Summer Institute.

The Teacher Perception Survey (see Appendix D) was also administered on Day 1 of the Summer Institute before the workshop began, at the completion of the 2016 Summer Institute workshop, following the September 2016, Saturday workshop, and again at the end of all Year 1 activities in January 2017. The Teacher Perception Survey consists of 64 Likert-type scale questions and two open-ended questions. This survey sought to uncover teacher attitudes and beliefs regarding aspects and modes of science teaching and included a demographic section, comfort level with 3D Learning and components, confidence level 3D Learning, and teacher beliefs about instruction and student learning. This survey is adapted from previous teacher belief surveys (Hunter & Agranoff, 2008; University of Michigan, 2011) and could provide insight into teachers' thinking about science learning and teaching and their personal beliefs, which influence teacher thinking and the instructional decisions they make.

Items from the Teacher Needs Assessment and the Teacher Perception Survey overlapped and directly related to 3D Learning were selected for a closer analysis to determine teachers' understanding and implementation of 3D Learning and Teaching. Some of these items (Q3.1, 3.2, 3.3, 3.4, 3.5, & 6 from Teacher Needs Assessment; Q16, 17.1, 17.2, 17.4, 17.5, 26.6, & 26.7 from the Teacher Perception Survey) asked about teachers' understanding of the individual components of 3D Learning such as the SEPs, CCCs, and DCIs. Other survey items asked about teachers' understanding of the integration of the components of 3D Learning (Q3.5 & 3.6 from the Teacher Needs Assessment; Q17.5 & 17.6 from the Teacher Perception Survey). Some of the selected survey items asked specifically about teachers' experience with and confidence in their ability to implement 3D Learning (Q2 & 4 from the Teacher Needs Assessment; Q17.7, 18.1, 25.8, & 26.5 from the Teacher Perception Survey). The rest of the selected survey items related to teachers' implementation of 3D Learning, including the use of phenomena to drive instruction (Q18.1, 22.9, 26.1, 26.5, 29.1, 29.2, 29.5, 29.8, 29.9, 30.1, & 30.6

from the Teacher Perception Survey). These items were matched from the pre-workshop data collection, post-workshop data collection, and post-project data collection to determine the level of change in teachers' understanding of 3D Learning and their ability to implement 3D Learning.

CBAM levels of use survey. The Concerns-Based Adoption Model (CBAM) Levels of Use Survey (see Appendix E) utilized in this study is from the CBAM Project (George et al., 2008) and was intended to measure participants' levels of use of a component of teaching or a new program as a means to determine at what stage of adoption of new ideas they currently hold. The levels of use are as follows: 0. Nonuse, I. Orientation, II. Preparation, III. Mechanical Use, IV. Refinement, V. Integration, VI. Renewal. Each of these levels has a specific behavioral indicator from which teachers select the most appropriate to their current practice. For this research study and the overall project within which this study is situated, the teachers were asked to identify their level of use, utilizing the descriptors in the CBAM survey, specific to the science and engineering practices, the disciplinary core ideas, the crosscutting concepts, the performance expectations, and three-dimensional learning in the classroom.

3D Learning perception survey items data analysis. Quantitative data analysis was conducted on the 3D related items selected from Teacher Needs Assessment and the Teacher Perceptions Survey. Statistical analysis of the 3D Learning perception items was performed to determine basic quantitative measures such as mean, median, mode, range, and standard deviation (SD) as well as to create a frequency distribution for each set of data in order to compare the frequencies of relevant scores, the associated standard deviations and for possible statistical significance. Based on this data analysis, teachers in each grade band (Elementary: grades 3-5, Middle School: grades 6-8, and High School: grades 9-12) were ranked in order of growth.

CBAM levels of use survey data analysis. Similar statistical analysis (such as mean, median, mode, range, SD, and the creation of a frequency distribution) were performed on the levels of use data self-reported on the CBAM survey. Pre-project workshop data were compared to the post-summer workshop data, and the post-project workshop data to determine the teachers' growth in implementation of 3D Learning and Teaching. Based on this analysis, teachers at each grade band were ranked based on the increase of their use and implementation of 3D Learning and Teaching. These data along with the 3D perceptions survey items data were used to select teachers to participate in Phase Two of this study.

Phase Two Overview. An instrumental case study approach was utilized for Phase Two of the study as this qualitative approach can provide insight into an issue through the investigation of the selected case (Baxter & Jack, 2008; Stake, 1995). The described quantitative data were analyzed and used to select the teachers who were involved in the targeted case to be studied and the related qualitative data collection portion of this study. The participant selection process for Phase Two and selection criteria will be discussed in more detail in the following section. The selected subset of teachers participated in using teacher generated artifacts from Year 1 of the project to construct a CoRe and related PaP-eR. These teachers also participated in individual follow up semi-structured interviews. These data were analyzed to provide a better understanding of their experiences and beliefs related to 3D Learning and Teaching. All qualitative data were collected during Year 2 and Year 3 of the project after the completion of Year 1 activities.

Participant selection. A small subset of the project participants (n=6) were selected and invited to participate in Phase Two of the study, the qualitative data collection. Teachers were selected based on the results from the quantitative analysis of the 3D Learning perception survey items pulled from the Teacher Needs Assessment and the Teacher Perceptions Survey, and the CBAM Levels of Use Survey. Two teachers per grade band (Elementary: grades 3-5, Middle School: grades 6-8, and High School: grades 9-12) were selected and invited to participate in the qualitative phase of this study. One teacher at each grade band was selected using the 3D Learning perception items analysis and one teacher was selected using the CBAM level of use data analysis. These teachers were selected based on achievement of relatively higher gains shown on the associated ranked list created from the descriptive statistical analysis. Based on this grouping, one teacher from each quantitative data category was selected from each grade level band (Elementary: grades 3-5, Middle School: grades 6-8, and High School: grades 9-12) for a total of two teachers per grade band (n=6).

Teacher generated artifacts and 3D CoRes. According to one PCK expert, “The application of knowledge to teaching can be found in the instructional plans that teachers create and in the reasons behind their instructional decisions" (Gess-Newsome, 2015, p. 36). Thus, this expert outlined two types of pedagogical content knowledge (Thought Processes and Teacher Practice):

- Thought Processes – "**The knowledge of, reasoning behind, and planning for** teaching a particular purpose to particular students for enhanced student outcomes" (Gess-Newsome, 2015, p. 36).
- Teacher Practice – "The **act of teaching** a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes" (Gess-Newsome, 2015, p. 36).

In addition to the Phase One surveys previously described, teachers constructed a series of instructional tasks using increasingly refined templates (see Appendices F through I). These tasks were created collaboratively between grade level teacher pairs using the online collaborative software Google Docs. This format allowed me, the researcher and PD facilitator, to view the revision history of the instructional tasks along with the progression of each task constructed by the teachers. These artifacts and various versions of instructional task documents, along with how they develop over time, provided insight into teachers understanding and usage of 3D Learning and their use of phenomena in instruction.

In conjunction with the instructional task documents, the grade level teacher pairs participated in a modified lesson study as described in more detail earlier in this chapter (Lewis et al., 2006) Teachers paired with a grade level partner and each constructed their own instructional task. One teacher implemented his/her instructional task while his/her partner and a CORPS project team member(s) observed. Following this observation, teacher pairs and project team member(s) debriefed the task using an interview protocol (see Appendix J). The instructional tasks were then revised based on the debrief feedback and the teacher's grade level partner would reteach the instructional task and provide additional feedback using the interview protocol questions to guide their feedback responses. The provided feedback was used to further revise the instructional task. This lesson study process was carried out for both teachers in the grade level pair and their corresponding instructional tasks. Most of the project participants took part in the modified lesson study. During the interview process, I, as the researcher, assisted individual teachers in reflecting on creating their 3D instructional task to construct a Content Representations (CoRes) set in the context of 3D Learning and utilizing the revised, teacher-developed phenomenon-driven three-dimensional instructional tasks. Using the CoRes focused on instruction set in the context of 3D Learning could uncover teachers' 3D-PCK.

A CoRe serves to capture, in the form of a set of propositions, a teacher's instructional approach and the reasons for enacting that approach with a specific topic, essentially, describing the big ideas to be taught, how they will be taught, and the reasoning behind these decisions (Loughran et al., 2012; Loughran et al., 2001; Loughran et al., 2004). Specifically, a CoRe refers to the teaching of a specific concept to a specific group of students (Loughran et al.,

Table 6

Sample 3D CoRe Template

Big Science Ideas/Concepts – (What is/are the targeted DCI(s)?	A	B	C	D
1. What do you intend the students to learn about this idea/concept? (What is/are the targeted PE(s)?)				
2. Why it is important for students to know this?				
3. What else you might know about this idea (that you don't want the students to know yet)				
4. Difficulties/limitations connected with teaching this idea				
5. Knowledge about students' thinking that influences your teaching of this idea				
6. Other factors that influence your teaching of this idea				
7. Teaching procedures (and particular reasons for using these to engage with this idea) (How will student engage in the SEPs and utilize the CCCs to investigate and explain Phenomena related to the DCI?)				
8. Specific ways you will use to ascertain students' understanding or confusion around the idea (How will you utilize Formative and/or Summative Assessments to evaluate if the student has met the targeted PE(s)?)				

2012). The modified 3D CoRe (see Table 6) was comprised of eight prompts or questions focused around a big science idea or concept, about which teachers respond to when planning for instruction. In this study, since I focused on 3D-PCK, the big ideas related to and could be used interchangeably with the DCIs from the 3D science standards. Most of the teacher-developed phenomenon-driven three-dimensional instructional tasks focused on one big science idea (DCI), and possibly one or two secondary related big science ideas (DCIs). The primary DCI was described in Column A and the secondary DCIs were described in Columns B-C in order of relevance to the central DCI.

Question One of the 3D CoRe allowed the teachers to unpack the big science idea [What do you intend the students to learn about this idea? (What is/are the targeted PE(s)?)]. Question Two made the connection of the importance and relevance of the concept to the student (Why is it important for students to know this?). Question Three required the teacher to think about the big picture in which the science topic fits into (What else you might know about this idea that you don’t want the students to know yet). Question Four served to identify any possible difficulties students could encounter during engaging with the topic (Difficulties/limitations connected with teaching this idea). Question Five forced a teacher to make connections from students’ prior conceptions and knowledge to the big idea (Knowledge about students’ thinking that influences your teaching of this idea). Question Six required instructional thought about contextual knowledge about students’ general pedagogical knowledge that influences the teaching approach (What other factors influence your teaching of this idea?). Question Seven allowed the teacher to use their previous reflections to plan instructional steps and strategies for their students’ learning experience (teaching procedures and particular reasons for using these to engage with this idea (How will student engage in the SEPs and utilize the CCCs to investigate and explain Phenomena related to the DCI?). Question Eight required teachers to think about the possible ways that student thinking can be uncovered and evaluated through the use of formative and summative assessments (Specific ways you will use to ascertain students' understanding or confusion around the idea (How will you utilize Formative and/or Summative Assessments to evaluate if the student has met the targeted PE(s)?).

A CoRe provides insight into a teacher's thinking about instruction and student learning and makes their PCK more visible (Loughran et al., 2004). Using the CoRe to make the teachers thought processes about instruction and student learning related to a specific 3D Learning task provided useful information about the decisions behind how teachers 3D-PCK translated into their classroom instruction.

3D PaP-eRs. Where CoRes gave insight into the thought processes of teachers' instructional decisions, a Pedagogical and Professional-experience Repertoire (PaP-eR) was utilized to examine the actual teacher practice related to the phenomena-driven three-dimensional instructional task (Gess-Newsome, 2015). A PaP-eR is a narrative constructed from the teachers' CoRe and the teacher's account of the implementation of the planned science instruction (Loughran et al., 2012). Questions Seven and Eight from the CoRe provided an opportunity to draw out rich details as they are able to elicit teachers' reflection and sharing their story of classroom practice related to the CoRe (Loughran et al., 2012). In this study, each PaP-eR focused on the 3D aspect of instruction. The 3D PaP-eR is written in such a way as to “elaborate and give insight into the interacting elements of the teacher’s PCK” (Loughran et al., 2012, p. 19) that makes this tacit knowledge accessible to others facilitating reflection on their own practices and possibly prompting change in their own instructional practice. According to Loughran et. al. (2012), “PaP-eRs bring the CoRe to life and offer one way of capturing the holistic nature and complexity of PCK in ways that are not possible in the CoRe alone” (p. 19). In the context of this study, I sought to bring to life the nature and complexity of PCK in a 3D Learning environment. Each PaP-eR is unique and can take different forms depending on the type and depth of PCK being portrayed (descriptions of classroom observations, narrative of teacher interviews, callout boxes, or documentation of teacher out loud thinking) and may be constructed from varying perspectives (teacher, student, or outside observer) (Bertram & Loughran, 2012; Loughran et al., 2012; Loughran et al., 2001). In this study the PaP-eRs took the form of an interview narrative with callout boxes to focus the reader on the ideas communicated by the teacher. Together the information from the CoRes and PaP-eRs provided a more complete understanding of the teachers PCK in a 3D Learning context (3D-PCK), and together more fully addressed RQ3 (How does teachers’ 3D-PCK translate into their classroom instructional practices?).

Follow-up interviews. To address RQ4, What experiences within a three-year 3D Learning focused professional development context can lead to growth in teachers' understanding and implementation of 3D Learning and teaching? and RQ5, What perceived outcomes resulted from participation in a 3D Learning- focused professional development program?, semi-structured follow-up interviews were conducted with the same subset of selected teachers that constructed CoRes and PaP-eRs. These interviews focused explicitly on the teachers' Year 1 experiences during:

- project activities
    - Summer professional development institute
    - Collaboration sessions
    - Saturday workshop
    - Workdays
    - Lesson study
- classroom implementation
- and project support.

A semi-structured interview protocol (see Appendix K) was developed to elicit information about the teachers experiences in the project that could have contributed to their growth in understanding and implementing 3D Learning and Teaching. Questions one and two were designed to activate teachers' reflection about their experience in the project and scaffold the teachers to think more deeply about their experiences that were most formative for them in relation to 3D Learning and Teaching. Questions three through five sought to elicit responses about teachers' confidence, attitudes and feelings, and their thinking about teaching practices as related to the project. Questions six and seven asked the teachers to reflect on experiences in their classroom implementation of 3D Learning and how their participation in the project have influenced their ability to implement 3D Learning. Questions eight and nine directly addressed research question four, asking explicitly what experiences have most strongly impacted their understanding of and ability to implement 3D Learning and Teaching.

Data analysis. The qualitative data collected after the completion of Year 1 of the CORPS project were analyzed to help expand on and explain the results from Phase One of this study. The meaning that emerged from Phase Two of this study provided a deeper understanding into the 3D-PCK of the participants. The teacher instructional task documents, related CoRes, lesson study observations, debrief interviews, PaP-eRs, and semi-structured follow up interviews were analyzed using a constant comparative method (Creswell & Clark, 2007; Glaser & Strauss, 1967).

To accomplish this analysis, the artifacts described above were coded to see what themes might emerge from the teachers' work centered on 3D Learning as the project progressed, and how those themes might be further strengthened or revised depending on the analysis of the lesson study debrief interviews and subsequent post-project semi-structured follow up interviews. I utilized printed copies of the qualitative data sources for each of the selected participants and colored markers to analyze the data using open coding (Merriam, 2009). The codes were recorded in a notebook and then transferred to sticky notes. I collaborated with another researcher familiar with 3D Learning and Teaching to perform axial coding by combining and grouping related codes (Merriam, 2009). From these groupings, themes and subthemes emerged related to the participants experiences during Year One of the project. By relying on a subjective researcher as a form of triangulation the validity of the findings was strengthened (Merriam, 2009; Stake, 1995). The themes that emerged from this analysis provided a way to describe PCK as it existed in a 3D context within a professional development program focused on 3D Learning in grades three through high school rural science classes.

Researcher Positionality

The fact that I as the researcher also served as the PD provider and mentor over the course of the project also may raise ethical concerns. As PD facilitator and project manager I held a position of authority in the eyes of the participants. As a researcher, it was necessary to make sure that I clearly communicated my role when I inhabit a specified researcher role. This reflection was an attempt to ensure that participants did not feel coerced to participate in the research study and that choosing to participate or not participate in the research study would have no effect on their participation in the professional development project. Additionally, as the CORPS project manager, it was necessary to reflect on my role of providing professional development to facilitate growth in 3D Learning and Teaching as well as the role of researcher. Self-reflection was important in order to determine how my roles as the researcher and as the project manager/PD facilitator related to the participants in the project and study (Milner, 2007; Salzman, 2002). This process was essential as my various roles of the researchers were invariably “embedded in the process and outcomes of educational research” (Milner, 2007, p. 389).

Summary

In Chapter Three, the methods used to collect and analyze data for this study were discussed (see Figure 9 for a visual representation). This study took place in the context of a three-year professional development program located in the Southwest region of the United States and focused on a group of 67 rural grade 3 through high school teachers transitioning to 3D Learning and Teaching (NRC, 2012; NGSS Lead States, 2013). This research focused on Year One of a three-year professional development project and utilized an explanatory sequential mixed methods approach that was carried out in two phases, Phase One (quantitative) leading to Phase Two (qualitative) (Creswell, 2013; Creswell & Clark, 2018). During Phase One, quantitative data collection occurred and included a teacher needs assessment, a teacher perception survey, and a CBAM Levels of Use Survey (George et al., 2008). These quantitative data were used to identify a subset of teachers who comprised the case to be studied. These teachers participated in Phase Two in which the qualitative data collection portion of the study, which included analysis of teacher generated phenomenon-driven three-dimensional instructional tasks, the correlated CoRes and PaP-eRs, and semi-structured follow up interviews all showcasing the possible 3D PCK of the selected teachers. These data were analyzed in order to capture the PCK of teachers in various degrees of transition to 3D Learning and will be discussed in detail in Chapter 4.

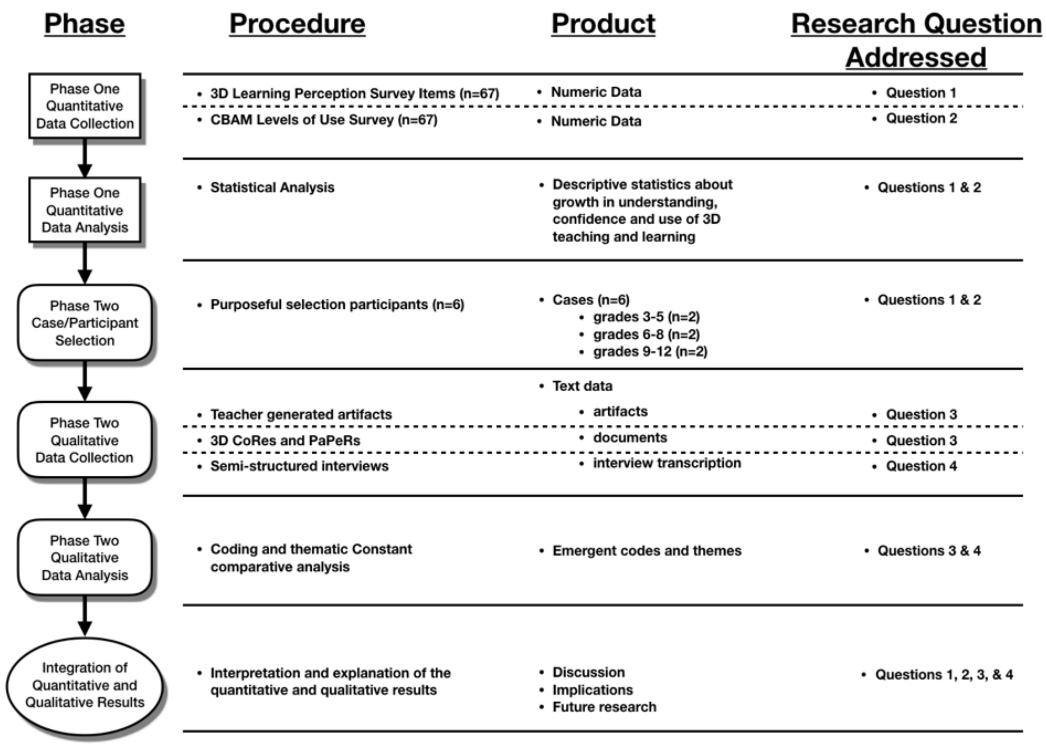


Figure 9. Visual Model for Explanatory Sequential Mixed Methods Study Implementation

Chapter 4: Findings

Introduction

This study was conducted to capture and describe the pedagogical content knowledge (PCK) of elementary, middle school, and high school teachers focused on transitioning to phenomenon-driven 3-Dimensional (3D) science Learning and Teaching. A two-phase, explanatory sequential mixed-methods approach was utilized to investigate the experiences of 67 rural science teachers, grades 3 through 12, who participated in an intensive three-year professional development program focused on 3D Learning and Teaching practices. This study focused on Year One of this project. In Phase One, quantitative data in the form of pre/post teacher perception surveys and pre/post CBAM Levels of Use surveys were utilized to select a small subset of teachers to participate in Phase Two of the study. During Phase Two, two elementary, two middle school, and two high school teachers participated in semi-structured interviews designed to uncover teachers' experiences in planning for and implementing 3D Learning and Teaching and any experiences that may have been formative in the development of their 3D-PCK.

Five questions were central to this study.

1. What are the characteristics of teachers identified with significant growth in self-reported understanding of 3-Dimensional Learning?
2. What are the characteristics of teachers identified with significant growth in the self-reported implementation of 3-Dimensional Learning?

3. How does teachers' 3D-PCK translate into their classroom instructional practices?
4. What experiences within the first year of a three-year 3D Learning-focused professional development context can lead to growth in teachers' understanding and implementation of 3D Learning and Teaching?
5. What perceived outcomes resulted from participation in a 3D Learning-focused professional development program?

The findings and analyses from this research study are presented in this chapter. The first section discusses the quantitative data and analyses that address RQ1 and RQ2. The first section also describes how participants were selected for Phase Two, the qualitative phase of this study. The second section discusses 3D-PCK as a framework for the study and provides qualitative analysis and themes addressing RQ3, RQ4, and RQ5.

Phase One: Results of Quantitative Analysis and Participant Selection

Participants in Year One of the CORPS project completed the Teacher Needs Assessment Survey (see Appendix C) and the Teacher Perception Survey (see Appendix D). From the Teacher Needs Assessment Survey and the Teacher Perception Survey specific items designed to measure comfort level and understanding of 3D Learning through a series of Likert scale items were selected for analysis. Additionally, the participants completed the CBAM Levels of Use Survey (Appendix E), which focused on the teachers' self-reported level of implementation of 3D Learning. These surveys were completed pre-summer workshop, post-summer workshop, and post-Year 1 of the project. The results of these surveys were each analyzed and used to create two distributions of scores for the participants that showed increased growth in understanding and implementation of 3D Learning. These lists were utilized in the participant selection for Phase Two.

RQ1: Characteristics of Teachers with Growth in Self-Reported Understanding of 3-Dimensional Learning.

To answer RQ1, "*What are the characteristics of teachers identified with significant growth in self-reported understanding of 3-Dimensional Learning?*" quantitative analysis was performed on selected items from the Teacher Needs Assessment Survey and the Teacher Perception Survey data to create a continuum of participants' growth in understanding from pre-project to post-project (see Table 7). At the beginning of the project a cohort of 67 teachers grades 3 through 12 completed a Teacher Perception Survey (see Appendix D). The Teacher Perception Survey included 22 Likert-type items targeting 3D Learning, of which the maximum total score was 136. Lower scores would indicate a lack of familiarity, understanding of, and confidence with 3D Learning and high scores would indicate increased familiarity and understanding of and confidence with 3D Learning. Teachers completed a perception survey with a small subset of these items (Questions 17.1, 17.2, 17.4, 17.5, 17.6, 17.7, and 18.1) following the Year 1 summer workshop; however due to the limited scope of this survey it was not utilized in the final analysis. Only 36 participants attended the final workshop at the end of Year 1 of the project. These 36

Table 7

Continuum of Participants Growth in Understanding Pre-Project to Post-Project

Growth in Participants' Understanding of 3D Learning	Participant Teaching Level	Years of Teaching Experience	Years of Science Teaching Experience
67	Elementary	20	20
63	Elementary	35	35
62	Elementary	18	18
62	Elementary	n/a	n/a
59	High	2	2
58	Elementary	12	12
58	Elementary	24	23
56	Elementary	2.5	2
56	Elementary	14	9
53	Middle	22	6
53	Middle	20	7
50	Elementary	7	6
50	Elementary	13	13
49	Elementary	7	3
49	Elementary	22	22
48	High	n/a	n/a
46	Elementary	11	4
45	Elementary	20	14
41	Elementary	37	37
36	Elementary	13	6
35	Elementary	4	1
33	Elementary	15	12
32	High	18	9
31	Middle	4	4
29	Elementary	5	5
27	Elementary	32	6
27	Middle	19	19
26	High	15	15
24	High	17	17
24	Elementary	19	16
23	High	19	19
19	Elementary	3	3
18	Elementary	30	30
15	Middle	12	12
13	Elementary	4	0
3	High	15	15

participants from the cohort completed the full Teacher Perception Survey again at the end of Year 1 of the project. As a result, only the data from these 36 participants were available for comparison and analysis. The participants' pre-project cumulative scores were compared to their post-project cumulative scores to find the amount of growth each individual achieved over the course of Year One of the project. These growth scores were then ordered from greatest to least to create a continuum of participants' growth in understanding of 3D Learning and Teaching.

Descriptive statistics were also generated from the continuum data (see Table 8) as well as a histogram displaying the frequency distribution for the continuum of participants' growth in understanding 3D Learning and Teaching data (see Figure 10). The range of participants' growth in 3D understanding was 64 with a mean of 40, a median of 43, and a standard deviation of 16.83 signifying that the increase in understanding 3D Learning and Teaching were more spread away from the mean. The distribution of growth levels is slightly negatively skewed, indicating that the growth participants experienced related to 3D Learning and Teaching tended to be larger.

Table 8

Descriptive Statistics of Continuum of Participants' Pre-Project to Post-Project Growth in Understanding

N	Minimum	Maximum	Range	Mean	Median	SD	Skewness	Kurtosis
36	3	67	64	40	43	16.83	-0.258	-0.987

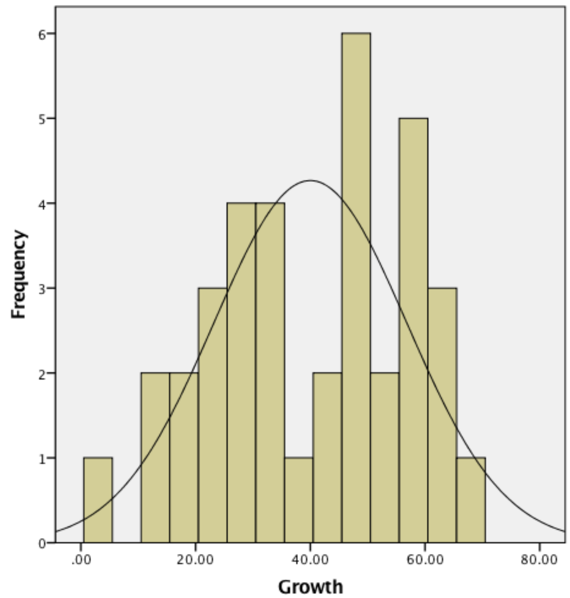


Figure 10. Histogram for Continuum of Participants Growth in Understanding from Pre-Project to Post-Project

The majority of the participants showing growth levels higher than the mean were elementary teachers (78.9%), 10.5% were middle school teachers, and 10.5% were high school teachers (see Figure 11). Of the participants showing growth levels below the mean, 52.9% were elementary teachers, 17.6% were middle school teachers, and 29.4% were high school teachers (see Figure 12). Although the majority of teachers in the project were elementary, it is notable that elementary teachers tended to show more growth in understanding of 3D Learning and Teaching than their middle school and high school counterparts.

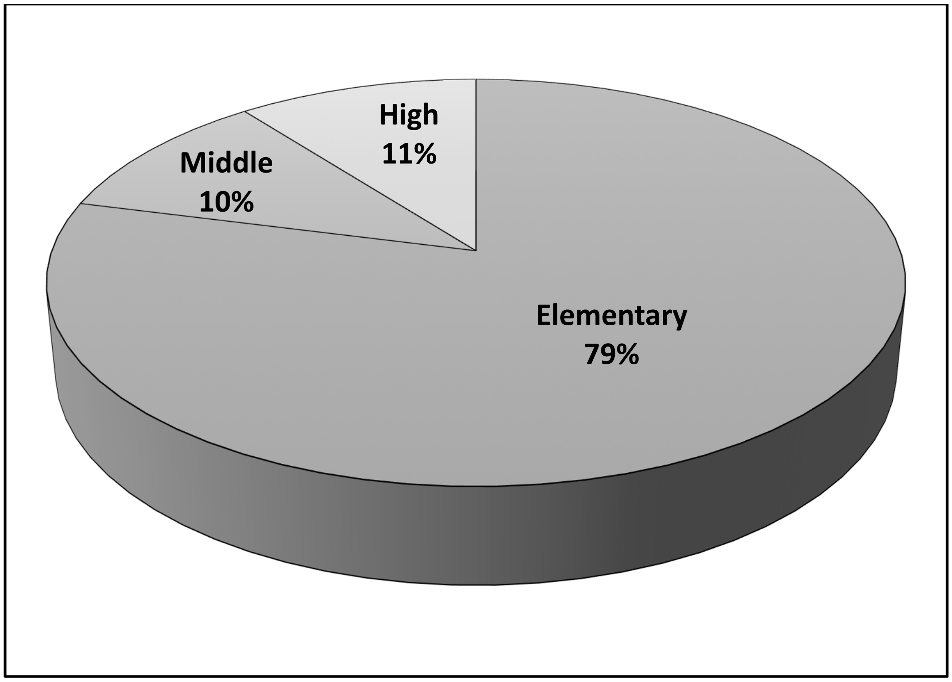


Figure 11. Percentage of Participants Growth in 3D Understanding Above the Mean at Each Grade Band

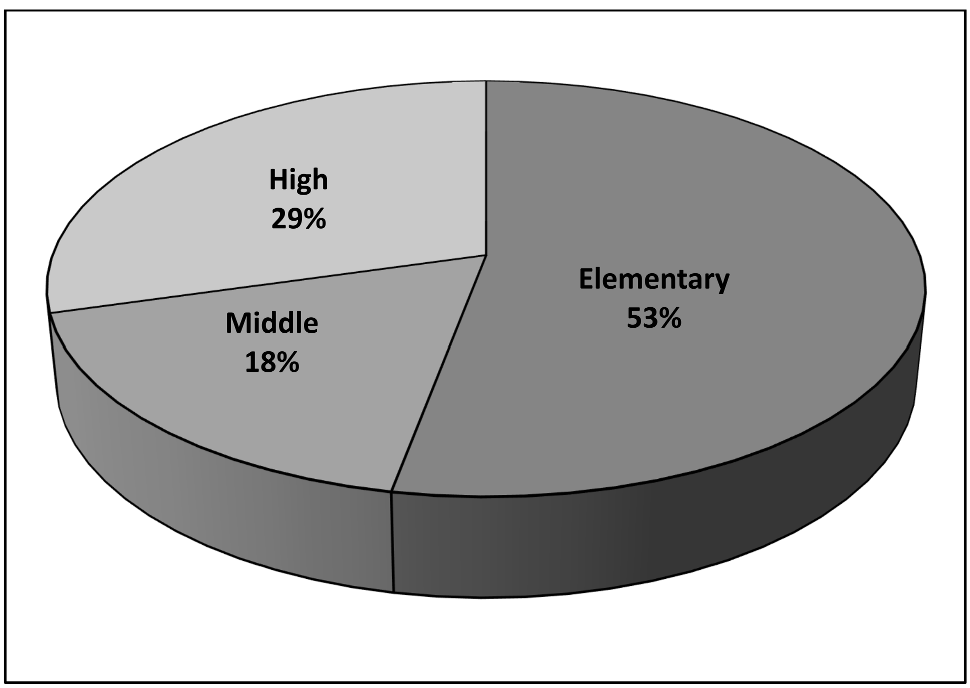


Figure 12. Percentage of Participants Growth in 3D Understanding Below the Mean at Each Grade Band

At the beginning of the project, participants provided basic information including number of years of teaching experience and number of years of experience teaching science. These data were analyzed to determine if any correlation might exist that could provide insight into the characteristics of the participants showing increased growth in 3D Learning and Teaching. When analyzing the participants' years of experience teaching and years of experiencing teaching science for correlation with levels of growth in understanding there was a weak positive correlation [r=0.054, n=36, p=0.763]. When analyzing the participants' level of growth in understanding and participants' year of experience teaching science there was a weak positive correlation [r= 0.082, n=36, p=0.643]. The correlations between the participants' teaching experience or science teaching experience and their growth in understanding of 3D Learning and Teaching was found to be non-significant.

Project participants also provided information regarding their previous professional development experience in relation to 3-Dimensional standards as well as professional development experience with the organization that planned and facilitated the professional development for the entirety of the project. These data were analyzed for the entire group. In addition, a focused data analysis for the ten participants in each grade band showing the most growth in understanding 3D Learning and Teaching was conducted as these participants would comprise the possible participant selection list for Phase Two of the study. When looking at the data, 36.1% of the participants had previously participated in professional development with the organization facilitating the three-year, 3D science-focused workshop. However, focusing on only the top ten participants showing growth in 3D Learning and Teaching at each grade band (elementary, middle school, and high school), this figure increased to 54.5%. A small minority, only 5.56%, of the participants had previously participated in other professional development, facilitated at either a state or local level, focused on understanding 3D science standards. When looking at the top ten participants showing growth in 3D Learning and Teaching at each grade band (elementary, middle school, and high school), this figure increased to 9%.

RQ2: Characteristics of Teachers with Growth in Self-Reported Implementation of 3-Dimensional Learning.

In order to answer RQ2, "What are the characteristics of teachers identified with significant growth in the self-reported implementation of 3-Dimensional Learning?" quantitative analysis was performed to create a continuum of participants' growth in implementation of 3D Learning and Teaching (see Table 9). Participants in the project self-reported their levels of use regarding the components and integration of 3D Learning and Teaching through the CBAM Levels of Use Survey (George, Hall, Stiegelbauer, & Litke, 2008) (see Appendix E) administered pre-summer workshop, post-summer workshop, and post-Year 1 of the project. The CBAM Levels of Use Survey consisted of five items each focused on a specific aspect of 3D Learning implementation. On these items participants rated their level of use from 0-6, a

Table 9

Continuum of Participants' Pre-Project to Post-Project Growth in Implementation of 3D Learning and Teaching

Growth in Participants' Implementation of 3D Learning	Participant Teaching Level	Years of Teaching Experience	Years of Science Teaching Experience
24	Elementary	7	3
23	Elementary	5	6
22	Elementary	n/a	n/a
22	High	n/a	n/a
21	Elementary	3	3
21	Elementary	11	4
20	High	12	2
20	Middle	19	19
20	High	15	6
20	Elementary	15	12
20	Elementary	13	6
19	Elementary	20	20
19	Elementary	n/a	n/a
19	Elementary	20	14
18.5	Elementary	35	35
18	Elementary	3	2
18	Middle	21	21
17	Elementary	18	18
17	Elementary	15	15
17	Elementary	5	3
17	Elementary	12	12
17	Middle	20	7
16	High	19	19
16	Elementary	2	2
16	Elementary	5	5
16	Elementary	8	2
16	Elementary	37	37
15	Middle	8	0
15	Middle	22	6
15	High	18	9
15	Elementary	22	22
15	Middle	19	19
15	Elementary	14	9
14	Elementary	4	4
14	Elementary	29	25
14	Elementary	24	23
14	Elementary	7	6
13	High	6	6
13	Elementary	4	4
13	Middle	7	7
12	High	17	17
12	Elementary	4	1
12	Elementary	3	3
11	Middle	12	12
11	Middle	35	33
11	Elementary	2.5	2
11	Elementary	32	6
10	Elementary	20	20
10	Middle	15.5	15.5
10	High	15	15
10	Elementary	5	5
10	Elementary	19	16
9	Middle	19	15
9	Elementary	13	13
9	Elementary	15	6
9	Elementary	4	0
8	Elementary	30	30
8	Middle	12	8
8	Elementary	11	6
7	Middle	10	10
6	Elementary	3	3
6	Elementary	26	26
5	Elementary	4	1
5	Elementary	9	8
2	Elementary	10	6
1	High	13	13
0	High	10	10

zero indicates non-use, one indicates orientation to 3D Learning, two indicates preparation for use, three indicates mechanical use, four indicates refinement of use in the classroom, five indicates the participant has integrated 3D Learning into their classroom by making deliberate efforts to implement 3D Learning, a score of six indicates that the participants has already established 3D Learning in their classroom and they are seeking ways to make the implementation more successful. On the CBAM Levels of Use Survey participants self-reported implementation for five areas relating to 3D Learning (SEPs, CCCs, DCIs, PEs, 3D Learning) resulting in a total possible score of 30. A low score on the CBAM Levels of Use Survey would indicate that the participant is at a low level of implementation. A higher score would indicate that the participant is becoming more proficient in their implementation of 3D Learning. All of the participants were present at beginning of the project; however, not all of the participants were present at each of the subsequent workshops. To calculate the growth in self-reported implementation of 3D Learning and Teaching for each participant, the level of use from the pre-project was compared to any level of use data from any of the following professional development workshops participants might have attended.

Through this analysis, I was able to calculate a change in level of use for each participant. Of the participants showing increases in levels of use of 3D Learning and Teaching above the mean, 70.2% were elementary teachers, 16.2% were middle school teachers, and 13.5% were high school teachers (see

Figure 13). When analyzing the data of those teachers with increases of levels of use below the mean, 60% were elementary teachers, 23.3% were middle school teachers, and 16.6% were high school teachers (see Figure 14). Similar to the results of participants understanding of 3D Learning and Teaching, these data indicate that elementary teachers showed the most increase in use of 3D Learning and Teaching.

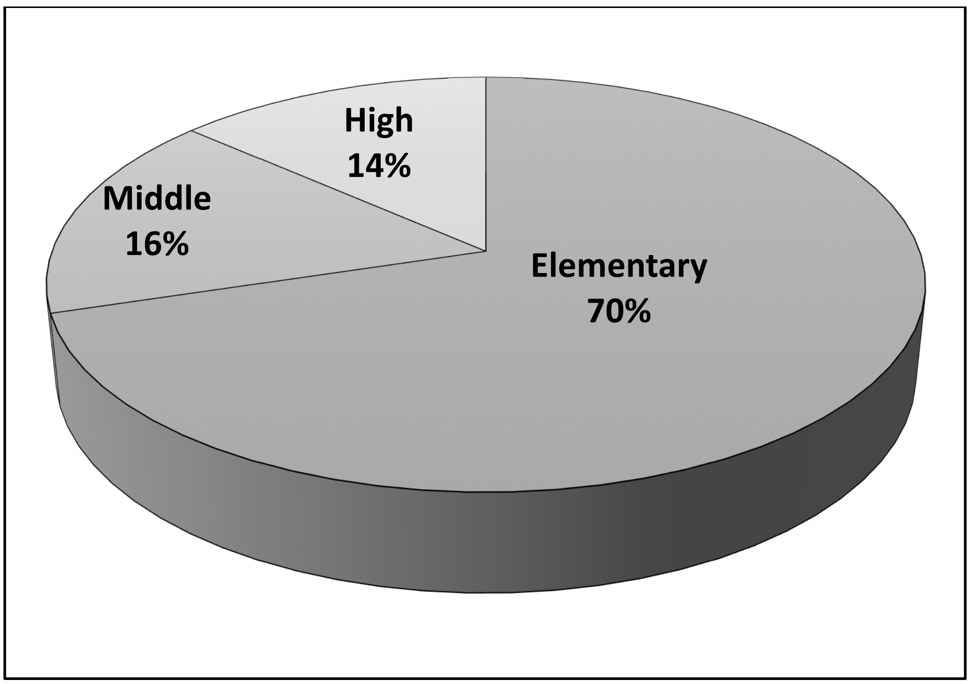


Figure 13. Percentage of Participants Growth in 3D Implementation Above the Mean at Each Grade Band

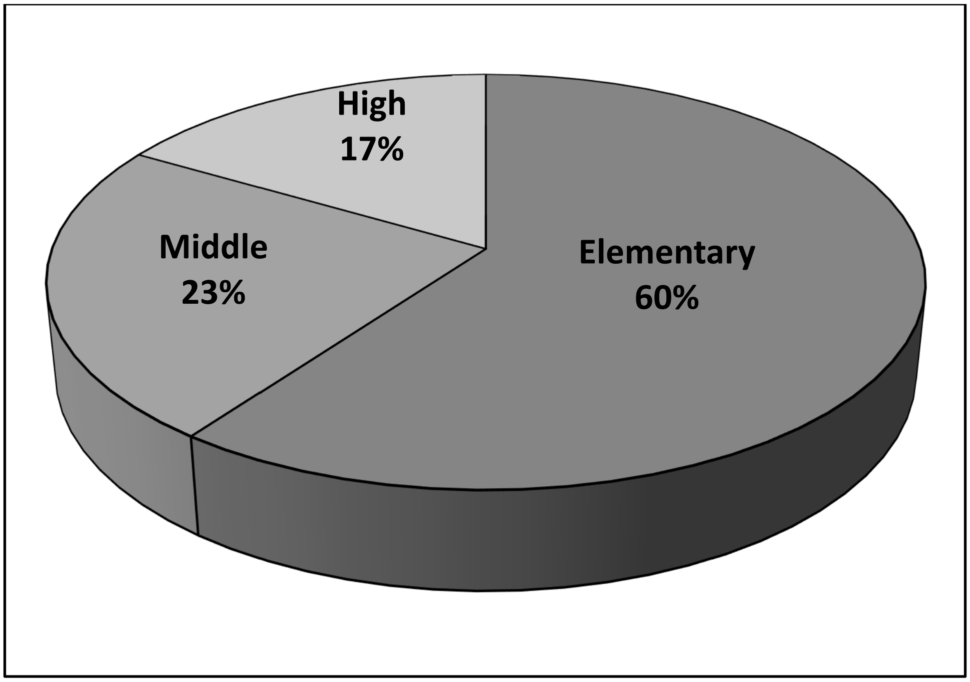


Figure 14. Percentage of Participants Growth in 3D Implementation Below the Mean at Each Grade Band

Statistical analysis was conducted to determine the descriptive statistical characteristics (see Table 10) and a histogram (see Figure 15) from the Continuum of Participants' Growth in Implementation of 3D Learning and Teaching. The range of the growth in participants' implementation of 3D Learning and Teaching was 24, the mean was 13.68, the median score was 14, and the standard deviation was 5.46 signifying that the majority of the increase in implementation was close to the mean. The distribution of the data was slightly negatively skewed indicating that most teachers showed higher increases in implementation of 3D Learning and Teaching in their instructional practices.

Table 10

Descriptive Statistics of Continuum of Participants' Pre-project to Post-Project Growth in Implementation of 3D Learning and Teaching

N	Minimum	Maximum	Range	Mean	Median	SD	Skewness	Kurtosis
67	0	24	24	13.68	14	5.46	-0.376	-0.286

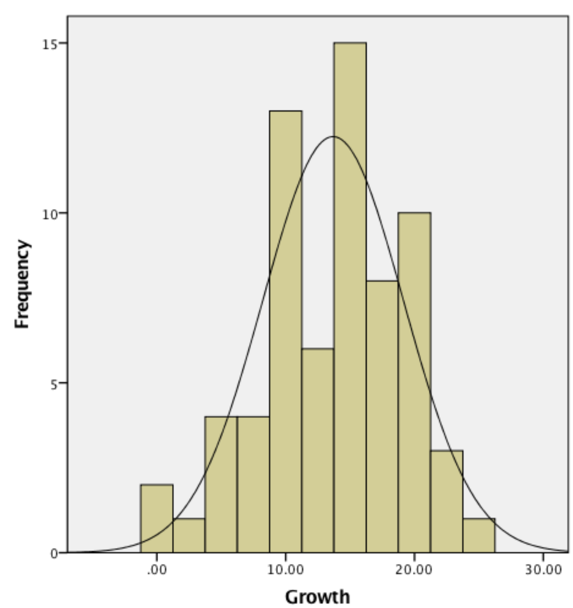


Figure 15. Histogram for Continuum of Participants Growth in Implementation of 3D Learning and Teaching from Pre-project to Post-Project

When analyzing for correlations between participants' increased levels of implementation of 3D Learning and Teaching and years of teaching experience and years of experience teaching science explicitly no significant correlation was able to be determined. There was a weak positive correlation between growth in implementing 3D Learning and Teaching and years of teaching experience [r=0.21, n=64, p= 0.869]. There was a weak negative correlation between years of experience teaching science and increased levels of implementing 3D Learning and Teaching [r=-0.15, n=64, p= 0.906]. When looking at only the top ten participants showing growth in implementation of 3D Learning and Teaching at each grade band (elementary, middle school, and high school), 40% had previously participated in professional development with the organization facilitating the three-year, 3D science focused workshop. A minority of the top ten participants, only 23.3%, had previously participated in other professional development, facilitated at either a state or local level, focused on understanding 3D science standards.

Phase Two: Qualitative Participant Selection.

A small subset of participants (n=6) was selected from the Year One cohort and invited to participate in the qualitative portion of the research study. Both the continuums from RQ1 and RQ2 were utilized to construct a set of lists of possible participants from elementary, middle school, and high school levels to invite to participate in the qualitative phase of the study. Pseudonyms were assigned to the participants on the lists. List One (see Table 11) was comprised of the participants with the most growth in understanding 3D Learning and Teaching. List Two (see Table 12) was comprised of the participants with the most growth in implementation of 3D Learning and Teaching. These lists were used to guide the purposeful selection of participants for the qualitative phase. One participant from each grade band from both lists were selected and contacted with an invitation to participate in Phase Two of the study. The

Table 11

List One. Top Ten Participants Showing Growth in Understanding of 3D Learning and Teaching in Each Grade Band

Elementary	Growth Score	Middle	Growth Score	High	Growth Score
1. Kara	67	1. Diana	53	1. Miranda	59
2. Cinthia	63	2. Gina	53	2. Megan	48
3. Barbara	62	3. Harriet	31	3. Barry	32
4. Abigail	62	4. Iris	27	4. Jessica	26
5. Camille	58	5. Jane	15	5. Lauren	24
6. Edith	58			6. Jill	23
7. Alice	56			7. Theresa	3
8. Debra	56				
9. Sarah	50				
10. Ella	50				

Table 12

List Two. Top Ten Participants Showing Growth in Implementation of 3D Learning and Teaching in Each Grade Band

Elementary	Growth Score	Middle	Growth Score	High	Growth Score
1. Irene	24	1. Ashley	18	1. Megan	22
2. Nancy	23	2. Gina	17	2. Miranda	20
3. Abigail	22	3. Diana	15	3. Lindsay	20
4. Barbara	21	4. Carla	15	4. Jessica	17
5. Samantha	21	5. Harriet	14	5. Jill	16
6. Wendy	20	6. Grace	14	6. Barry	15
7. Crystal	20	7. Lisa	13	7. Clark	13
8. April	19	8. Jane	11	8. Lauren	12
9. Kara	19	9. Bruce	11	9. Theresa	10
10. Ava	19	10. Lena	10	10. Peter	1

purpose of this process was to invite the individual participants showing the most growth.

From List One, Kara was invited as the elementary participant and she agreed to participate. Ultimately, Jane was the middle school participant selected from List One. Diana was not chosen as she was selected as the middle school participant from List Two. List Two participant selection will be discussed later in this section. Gina was not chosen as she discontinued her participation in the professional development program since Year One and has taught in a subject area other than science. Harriet was contacted and invited to participate but declined. Iris was not invited, because during Year One of the project she did not allow project staff to observe any 3D instructional tasks. As a result, data for those instructional tasks do not exist and she would not be an ideal candidate for the qualitative phase. For the high school level, Jill was selected to participate in the qualitative phase. Similar to Diana, Miranda had been selected as a participant from List Two. Megan was not chosen as a participant, because after Year One of the project she moved to a different school. Barry, Jessica, and Lauren declined to participate.

From List Two, Irene was invited from the elementary level and agreed to participate. From the middle school level, Ashley was invited but declined due to schedule conflicts. Gina, as previously mentioned, had left the professional development program since Year One and has taught in a subject area other than science since. Diana was invited from the middle school level and agreed to participate. For the high school level, Miranda was invited and agreed to participate in the qualitative phase of this study. Megan was not selected because, as previously discussed, she had moved to a different school after Year One of the project.

Results of Qualitative Analysis

Introduction

The qualitative data, including teacher generated artifacts, such as the teacher constructed 3D instructional tasks (see Appendix L for exemplar), 3D Content Representations (CoRes), and semi-structured interviews were combined and analyzed using an open coding constant comparative method (Creswell & Clark, 2007; Glaser & Strauss, 1967; Merriam, 2009) to generate emergent themes relevant to the research questions and were recorded in a theme chart to organize the findings (see Appendix M for exemplar). A 3D CoRe (see Appendix N for exemplar) was utilized to facilitate each participant to reflect upon their planning for 3D teaching as they constructed their 3D instructional task during Year One of the project. Additionally, each participant also reflected on how the 3D instructional task played out in the classroom as it was implemented using a 3D instructional task reflection sheet (see Appendix O for exemplar). Following this reflection on 3D instructional task implementation, each participant responded to a series of open-ended, semi-structured interview questions (see Appendix K) regarding their experiences in the first year of the 3D focused professional development project. Each of these data was analyzed to generate themes related to RQ3, RQ4, and RQ5 and relevant to the 3D-PCK framework. Three themes emerged from the qualitative analysis: Evidence of Growth, Growth Support Structures, and Driving Motivation. Firstly, an overview of each of these themes related to RQ3, RQ4, and RQ5 are briefly described to provide context as the theme results are presented. Secondly, after the overview of a theme relevant to the RQ is discussed, more detailed results for each sub-theme and code are presented.

RQ3: Teachers' 3D-PCK Translated into Classroom Instructional Practices

In order to answer RQ3, "How does teachers' 3D-PCK translate into their classroom instructional practices?", the qualitative data were analyzed for emergent themes. These themes and related sub-themes and codes were then reviewed for connections to each of the research questions. Theme 1: Evidence of Growth, centered on instances when participants described 3D Learning experiences they planned for and implemented in their classrooms and is relevant to RQ3. These descriptions served as evidence of participants' growth in understanding and utilizing 3D Learning and how their beliefs about teaching and student learning have shifted from their instructional practices and beliefs before participating in Year One of the project. In the following section, Theme 1: Evidence of Growth, is discussed in more detail and the results are presented.

Theme 1: Evidence of Growth.

Through open coding analysis (Merriam, 1998) multiple evidences of teacher growth in understanding and implementing 3D Learning and Teaching were identified among the six qualitative participants (see Table 13). Six common codes and one subtheme with four codes emerged. The first common evidence of growth in 3D Learning in these teachers was the idea that participants started the project expecting to be bored or that what they would

Table 13

Theme One from Qualitative Analysis

Theme 1: Evidence of Growth		
Codes		**Description**
Started Project Overwhelmed/Frustrated/Bored		Participants described being overwhelmed, frustrated, or expected to be bored upon starting the summer workshop. Descriptions often proceed to a realization about experience in project year one.
Being a Facilitator vs. Teacher		Participants described their current teaching role as facilitating student learning rather than direct instruction.
Students Develop Concept for Themselves		Participants described instances in which students were given the opportunity and instructional support to develop scientific concepts for themselves through investigation and collaboration.
Students Experience Concept		Participants described instances in which students were allowed the opportunity to experience scientific concepts for themselves either directly or indirectly.
Previous Style of Teaching vs. 3D Learning		Participants compared their current teaching style as more student centered and experiential when compared to their previous teaching style which centered on direct instruction utilizing lecture, bookwork, and worksheets.
3D Teaching in Practice	**Examples**	Participants described specific examples of 3D Learning occurring in their classrooms.
	Relevance to Students	Participants described instances in which they chose 3D Learning experiences and phenomena that directly relate to their students' lives and taps into their cultural funds of knowledge.

	Integration (cross curricular/interdisciplinary related to daily pressure and requirements)	Participants described instances in their planning for and implantation of 3D Learning experiences in which 3D Learning allowed them to integrate other disciplines.
	Perceptions	Participants describe their personal perceptions about how 3D Learning is occurring in their classroom and what results their students are experiencing.

experience would not be very relevant to their teaching practice. Grouped with this evidence was the idea that many of the participants were frustrated and in a state of disequilibrium at the beginning of the project due to encountering the challenge transitioning to 3D Learning. But, these same participants that described expecting to be bored, overwhelmed, or frustrated went on to explain their progression from a state of disequilibrium to adaptation (Bybee & Sund, 1982; Marek, 2008; Marek & Cavallo, 1997) regarding 3D standards and planning and implementing student learning experiences from a 3D Learning philosophy.

The second common evidence expressed by participants was the idea that they have transitioned to be more of a facilitator instead of the traditional role of teacher. The traditional teacher functions from a teacher-centered viewpoint, whereas these participants indicated that they now more often function from a learner-centered perspective (Schiro, 2013). In this role, the teacher focuses learning on the student and their experiences, interests, questions, and natural curiosity. The teacher allows these aspects of the student drive learning and the construction of new knowledge.

The third common evidence, directly related to the second, was the idea that the participants, when planning instructional learning experiences, designed the learning experiences so that students had to develop the scientific concept for themselves through collaboration and investigation. The fourth common evidence, related to both the second and third evidence, was the idea that participants specifically plan for and implement student learning experiences in which the students have the opportunity to experience the scientific concepts first hand for themselves. The fifth evidence described by participants was in the way that each of them described their previous teaching practices compared to their current teaching practices. Many of the selected participants expressed that their current style of teaching differs greatly from their previous style of teaching before the project in that their previous teaching consisted of relying heavily on lecture, textbook, and student practice through worksheet and their current teaching style focuses more on providing opportunities for student to construct knowledge for themselves through experience and collaboration.

One sub-theme emerged, which provided insight into the actual teaching practices of teachers actively transitioning to 3D Learning and Teaching practices. Contained within this subtheme are specific examples of teachers attempting to transition to and implement 3D Learning and Teaching, teachers being explicit in selecting phenomena and phenomena driven investigations that are relevant to their students and their cultural funds of knowledge (Lee, Miller, & Januszyk, 2014), examples of teachers explicitly planning for integrating other subject areas (i.e., mathematics, English Language Arts, social studies, art, music, etc.), and teachers describing their perceptions of 3D Learning and Teaching as they have been planning and implementing it in their classrooms.

Results.

Feeling overwhelmed or frustrated. Most of the participants described that their experience when the workshop began was full of feelings of being overwhelmed or frustrated. These feelings arose from encountering new three-dimensional science standards that were quite different from previous standards which requires pedagogies different from previous standards which were content-focused (Moulding, Bybee, Paulson, & Pruitt, 2015; National Academies of Sciences, 2015; National Research Council, 2012, 2015; NGSS Lead States, 2013). Irene, the elementary participant with the largest self-reported growth in 3D Learning and Teaching, when talking about this experience, admitted,

> Well, at first it was scary. You know, nervous and when you guys started it was really like, I guess kind of like we were rubber bands and you were stretching us and a few times you know we snapped back to that regular teacher, that typical teacher, I've got to teach style. And I know that it took you guys a while, or it took me a while to get that student focused concept in your mind about what it means to not teach, to be a facilitator. So, it was scary and once we started going, 'oh' ok I can see what we're doing. It really was like your eyes pop open, I mean. And then you know

> you start thinking about the lesson that you have to do. And of course, that's scary because you know we've gone through it with you guys. But then to take it and do it on our own, or on my own. Oh my gosh, how is that going to happen? How would I even begin to do that when I'm not sure that I really understand? You know I can be lead but, can I lead?

Kara when discussing the beginning of the project stated,

> I'll be painfully honest the first two days I walked into it. I thought this is the most ridiculous thing to have to come sit through. Why am I sitting here and being told how to read a science lesson? And then as we started working through it and doing more of the stuff, with the other teachers and with the different instructors, and seeing what their outcomes were and what they wanted. And just seeing that it was okay to be excited about science." Diana also expressed a similar experience, "I think in the beginning it sounded overwhelming, totally overwhelming. Oh my gosh, I'm on board with this but I don't think everybody else will. But then I think, after I implemented a few that we had done that summer. And after doing those a few times and then seeing how the kids reacted differently to my different teaching. That just made the fire even bigger within me."

Likewise, Jane discussed feeling of apprehension at beginning this project,

> Well the first day was like any first day, I was overwhelmed. There was all this new stuff, and what have I signed up for? This is three years, what is this going to be? But we were able to backtrack and kind of baby

step into it and it was an eye-opening experience because I thought, I thought I went to a workshop and knew how to teach these new standards. And that first day I realized that I didn't know anything. But now, now I feel like I could teach a workshop. So, not that I want to but at least I feel like I could.

Miranda spoke specifically about being able to understand the new 3D standards,

> Well the very first day was very overwhelming because there is a new way to read these standards and I have seen the standards the year before, but I didn't know how to read them or what the different colors were or what anything meant. So first it was very overwhelming and then it went from knowing what it was to how to read it to how to implement it. To now it's just very easy to use.

Jill reflected on the idea of frustration from a slightly different perspective,

> Hesitation. Frustration. I know I need the standards, the new standards and how they differ from [previous state science standards] skills. [previous science standards] were ridiculous, ridiculous. But the new standards incorporated multiple aspects of learning. I knew I needed that as far as learning how to do that. But, it’s that hesitancy as far as learning something new. When you're far into your career do you really want to change? Do you want to be successful? Yes, you do, and you have to. Kids change all the time. I mean we get older, but the kids still don't know this stuff. But the way that they actually process information

> that changes, just due to technology. So, I think it was a little frustration as far as on my part. Once we got the lesson format. There was a lot of frustration in there for me. I just couldn't get the format down. But being able to find that it’s, I think it's a little bit easier now and I think even with, as the year progressed and incorporating into the classroom it got a little bit easier.

Each of the participants interviewed in one way or another described starting the project being overwhelmed or frustrated with the newness of 3D Learning, the new 3D science standards including the format, how to read them, what each dimension was and how to teach them. However, as each participant further elaborated on their experience in the project they discussed how this feeling of frustration and being overwhelmed began to change to a state of comfort with 3D Learning as they experienced and implemented 3D Learning for themselves and in their individual classrooms.

Being a facilitator vs. a teacher. When reflecting on their experiences related to transitioning to and implementing 3D Learning all of the participants communicated that the way in which they teach has shifted from a tradition role as teacher centered, which they described as being the “teacher”, to a more student-centered style of teaching in which the teacher functions more as a facilitator of student learning. Each participant either directly referred to being a facilitator or indirectly by describing a teaching situation in which they functioned in a way that served to facilitate student thinking and knowledge construction.

Irene, when discussing implementing her first instructional task, described characteristics of thinking, planning and implementation aligned to a facilitator, student-centered teaching style, “I mean I was trying to hold back and did not want them to have the information that it was a sink hole and wanted them to develop that [concept] over the course of the experiment.” She went on to discuss limitations when planning for and implementing her 3D instructional task,

> I guess the limitations we're really trying to put it all together and not give them too much information because the ‘teacher’ in you wants to teach first, rather than let them discover on their own. So, trying not to give them that traditional teacher spiel. You know let the lesson unfold itself. So, I think that was the difficult, the difficulty and the limitations is trying to keep myself from being the teacher and let them be the discoverers.

When Irene reflected specifically on planning for utilizing the SEPs and CCCs in instruction and how her 3D instructional task actually utilized these during instruction she was more explicit about being a facilitator rather than a traditional “teacher” stating that,

> I think they (SEPs and CCCs) were the basis. Because, when you're developing your lesson and doing the crosscutting concepts and the science and engineering practices, that's kind of the basis for how you develop your lesson. Because you're not asking the questions. They're asking the questions. You're not developing the model. You're just giving them the tools to do it themselves. You're not investigating, you're

> facilitating their investigation. So, it all goes hand in hand in developing your lesson so that you kind of remove yourself as teacher-student and be more a facilitator-engager.

Similarly, Kara during her reflection on planning and implementing her 3D instructional task, described characteristics of a teacher facilitator,

> It's just the kids exploring and having to put the information in their own words. The kids having to present it back, and basically turn the kids into the teacher. Instead of me teaching them, they're teaching me. So, I've turned them into somebody that gets to find information and share the information and I don't have to do it. I don't have to stand the front the room and talk to them and do the old Peanuts 'wah wah wah' sound. I mean, I let them do it and they get to share and then I'll say hey why don't you go see if you can find out something else. See what else new you can find. And with that piece, just that turning them into the instructor, they learn more.

Through this Kara expressed that she had begun to change her thinking about teaching toward a more inquiry mode of teaching.

Diana was much more explicit in describing her transition from a traditional style of teaching to a student centered as she began to plan and implement 3D focused instruction. Diana described still being in the process of moving toward more student-centered learning,

> I feel like I've become more of the, not necessarily the teacher, but the one who, and I don't want to say facilitator, because I'm not totally there

> yet. I would say in between those two. Where I've given you the basic information. Show me that you can find some more information based on this and let's build from that.

She showed great self-awareness through reflecting on her personal teaching practices and how her practices were progressing as she made the intentional effort to transition to pedagogies consistent with 3D Learning.

Jane brought up the idea that she, and other teachers, have been trying to make the shift to inquiry teaching for some time and she discussed the difficulty associated with that transition,

> And so, it is a shift of coming up with cool stuff to try to make it more discovery. Which we've been trying to do for years. But there was a big stress on inquiry. And so, you want to make it more inquiry, but at the same time, we were never taught that way. We were taught, these are the notes and so it is probably easier for some of the newer teachers. But it's harder for us to totally change how we teach the way we were taught.

Jane then talked about her experience of transitioning to 3D focused, student-centered pedagogies,

> They do share more, and I teach less this this way. I plan more but teach less. I'm talking less and that's been totally weird. You just coming in as a teacher. Every year you have your whole, I have my whole spiel on cells and I have my whole spiel on body systems. I know I can give them a whole lesson. I can write notes verbatim. I don't have to look at it and I

> know this stuff. But now I'm not really supposed to do that. I can do that if I want, but first we have to discover it and first I have to engage them.

Jane went on to describe her experience with teaching from a facilitator role,

> Because they're all engaged and they're all working and trying to come up with their experiment. So, you just have to walk around and be the facilitator. So, you know, it's a different kind of teaching you're not you know fussing at kids for not working. You're not teaching them long lectures. You're walking around and making sure that they're trying to answer the question you've given them.

Jane was able to reflect on and communicate about her experiences and difficulties when planning and implementing 3D Learning.

Miranda also discussed on of her experiences in implementing 3D Learning, “Well it wasn't reading out of the book and answering the questions. I was actually making them think about things.” Similar to Jane, Miranda also discussed difficulties with implementing 3D Learning with her students, “And a lot of my students have a problem thinking it out they want to just regurgitate.” In response to this resistance Miranda conveyed how went about trying to facilitate student thinking about the concept, “So, it's not always. ‘Is that the right answer?’, ‘What was your thinking?’, ‘Why did that happen’, and ‘Why did you think that?’” She recounted that this type of teaching made her students construct the concept for themselves, “I think it is because they actually got to do something with the information and they had to think about it to be able to process." Jill also utilized guiding questions when implementing 3D Learning to facilitate student thinking about the DCI concept,

> A lot of that was just personal conversation as they were going through their work and going group to group to group. Asking them specific questions. 'What have you found?', 'Why do you think this one looks like this and this is this way?', 'What would happen if this actually, if the temperature actually increased so much, is this still going to happen?' I think it was just more questioning. Just providing questions in order to get them, you know, thinking of other factors.

Students experience and develop concept for themselves. Directly related to the participants moving towards becoming facilitators of student learning was the participants describing planning and providing opportunities for students to experience and develop scientific concepts for themselves. In these instances, the participants were less explicit as they talked about student-centered learning and gave examples. Irene spoke specifically about planning for the students to directly experience the science concept,

> I thought about, and as I was looking for the activity, I wanted it to be something that they could experience while they were doing it. I think that is the challenge with this model of teaching. Because I feel like even when we were in class you know it's, it's you're experiencing that lesson and that's what brings you to the conclusions you need to get.

This is also reflected in Irene's view of science, "You know science is not book and paper learning, science is experiencing." When Irene reflected on how the

3D instructional task was carried out in the classroom she also pointed out that the students were responsible for developing the concept,

> They had to build the experiment. They would each go around and dump on the experiment and observe what happened. They would write down then what they were seeing. And then based on what they had seen from the picture, based on what they were experiencing in front of them, kind of led them to their conclusion.

Kara also expressed how her teaching has changed so that students are experiencing and developing the concept for themselves,

> I like shifting my way of thinking and teaching to more student expression and experiential learning. It is not about giving them information but having them explore the concept on their own and investigate it and then being able to come to their own conclusions about things.

Kara further elaborated on this idea,

> I like shifting my way of thinking and teaching to more student expression and experiential learning. It is not about giving them information but having them explore the concept on their own and investigate it and then being able to come to their own conclusions about things.

Diana also thought about how the 3D approach to teaching helped her students take ownership of building the concept themselves, “It helps them ask more questions and get them more engaged in what we're talking about and have a little bit of ownership if they find something that is related to that phenomena.”

Jane reflected on a specific lesson in which she had planned for her students to develop the idea of faunal succession through experience, “I tried to make it more visual and self-discovery as much as I could make succession.” More generally Jane conveyed her perspective on utilizing 3D focused pedagogies, “I'm teaching more science and less notes.” These sub-themes also were evident in Miranda’s thinking and planning for student learning, “Well it wasn't reading out of the book and answering the questions I was actually making them think about things. Well I was thinking I wanted to give them enough room where they might struggle and make mistakes.” When asked how using 3D Learning helped her students she stated, “I think it is because they actually got to do something with the information and they had to think about it to be able to process [the concept].” They both expressed that in planning instruction from a 3D centered position caused them to shift the responsibility of constructing meaning around a concept to the students as they experience and interact with the concept.

This same idea was communicated through Jill’s reflections on using 3D Learning, “The task forced them to generate an investigation to test their ideas which requires them to generate questions and evidence.” Jill talked about how the students had to work to make meaning of the science ideas, “I think they were engaged because the students had not experienced it before. The students had to work for the explanation.” She said that causing the students to do the work of constructing meaning for themselves led to the students to more meaningful engagement with and understanding of the concept, “I think they were engaged because the students had not experienced it before. The students had to work for the explanation. They are actually learning because they've already applied it." Jill went on to describe how she has begun to utilize phenomena in her classroom to help facilitate students sensemaking of science concepts, "I've done this where you just find a phenomenon and say hey what's going on? And then we work through it. And the kids can go from there." Each of these teachers appear to have moved from a position of teacher centered learning to student centered learning through the process of planning and implementing 3D Learning and Teaching in their classrooms.

Previous style of teaching vs. current style of teaching. One of the biggest evidences of growth in understanding and implementing 3D Learning and Teaching for these participants was that each of the participants went back and contrasted how they teach currently focusing on the three dimensions to guide their instruction with how they previously went about teaching. One pattern that emerged was that many of the selected participants previously relied heavily on the textbook to guide their teaching as well as the textbook being the primary way that students experienced science learning. However, as they have begun to transition to 3D Learning and Teaching most of the participants described how they have moved beyond the textbook. There was excitement in their voice as each of these participants reflected in this shift in their teaching practice.

Irene stated,

> You know you read a book you give marginal information. You write it down in a fill in the blank. Not exciting. Not wonderful. But you see a picture and you make observations and you have an experiment in front of you. That really opens your eyes to things you didn't even know you knew and yet based on things you knew kind of direct you to things you didn't know. Which is exciting, engaging. That asking the questions, the doing the experiment, the looking for the patterns to bridging gaps. It all happens.

Diana in describing her old teaching said, “My old teaching was. There's the book. Read the chapter. Do the worksheet. Watch a video.” But described her current teaching as, “Constructing explanations, designing solutions, asking questions, carry out investigation, analyzing and interpreting data – this is guided inquiry.”

Likewise, Jane described her reliance on the textbook previous to participating in the project,

> Before, my principal told me engage all learners. So, I would read a book one day or I would do a lesson and I have them take notes and then I would watch a video on it. And I would teach like I was taught, and I would tell them what to do and then we would do a lab on it.

and,

I truly have used the book as a crutch. And so, it's only this year that my students can tell you we use the book when I was gone and there was a sub. Before we were in that book every chapter.

Jane discussed her teaching now as,

I tried to get away from that sometimes, because you're supposed to teach inquiry. But I didn't I didn't do it a lot. And this time, with these three years [in the project], I know how to find phenomenon, how to find pictures to put it in as bell work, and how to find probes, to be able to write probes like Page Keely and have lots of choices and start sticking them in so that you were getting students to think, constantly. And you're constantly making sure that they are engaged. And this time I'm using phenomena and different investigations and activities. We were able to totally stay away from that [reliance on the textbook]. And I was able to use, OK as you're doing this activity go to this book and this page for help if you need to. And it was totally a resource. So, there was a lot less lecturing and a lot less reading and more science.

Miranda was more explicit in describing her shift to the standards guiding her instruction versus the textbook being the driving force. Miranda stated,

In the past I looked chapter to chapter. Well now I look at the standards and I go OK; these two chapters talk a little bit about the standard. What else can I throw in there for them to do that'll cement this law [concept] together? And so, it went from just the chapter in the book to the standard driving what I'm going to do.

Jill indicated a similar experience with her previous teaching style, “Open to Chapter 5. Read the first paragraph. What do you think, you know? I mean it's, I don't know, that is kind of boring.” Whereas Jill’s teaching now is much different with incorporating 3D Learning and Teaching,

> More on the positive side. Just because it's allowed me to incorporate multiple facets. I don't know, it's not as linear as it used to be. Like, chapter one, chapter two, chapter three, chapter four, you know. Now it might include their book as a reference but it's multiple chapters. You go from here. Then you go to this chapter. Look at this. OK, well how do you explain this? And then relating it to your real world.

Each participant to some degree has moved away from relying on the text book as the singular mode of instruction.

The other idea that the participants expressed in contrasting their old teaching style to their current teaching style was the idea that their students are more directly involved in the learning process. Kara talked about this shift from the traditional teaching role to a 3D facilitator,

> I don't have to have a fill in the blank page for them to fill out. I don't have to have multiple choice test for them to do. I can get those kinds of grades and those kinds of activities with them verbally teaching me what they've learned, and with them writing their paragraphs with what they've learned, and with them presenting it back to me. And I don't have to do the stand up and do the lecture. I have them find it and they get excited because they found it on their own.

Jane also talked about how her teaching has changed in this way. Jane discussed how she is trying teaching methods that she previously would have been hesitant to try,

> In trying to teach 3-Dimensional I've done more labs. And the labs have had more of an engineering aspect. Whereas before I never even had that. Before I came to this three-year journey I never would just give my students a bunch of supplies and tell them to design their investigation and I'm doing that a lot. Where I'm having them design their own investigation.

Jill recounted the same experience as well,

> It's probably tried to get me away from straight lecture and incorporate more group activities, more student discussion. We have always had student discussion in my room, but I think I've incorporated more activities where they are doing the work. And finding out the information more than me just telling them.

These ideas exemplify the shifts that the selected participants have made in their instructional practices as they have intentionally worked toward teaching and learning from a 3D framework.

3D Teaching in practice. In addition to the participants describing how their teaching practices have changed as they have begun to implement 3D Learning and Teaching they also provided concrete examples of 3D Teaching from their experience with implementation, discussed how they have specifically planned to make 3D Learning experiences relevant to their students, described their perceptions of 3D Learning, and talked about how 3D Learning and Teaching provided opportunities to integrate other concepts and disciplines into student learning experiences. Each teacher first planned a 3D instructional task documenting their thinking and planning on a “3-Dimensional Instructional Task Narrative” (see Appendix L for exemplar). After teaching their 3D instructional task, each teacher participated in a debrief interview facilitated by project team member and documented on an instructional task reflection sheet (see Appendix O for exemplar). Post project each teacher completed a 3D CoRe (see Appendix N for exemplar) in order to reflect specifically on their thinking about and planning for implementing a 3D instructional task that might provide explicit insight into PCK in a 3D instructional context. In addition to the 3D CoRe, each of the selected participants also recounted their experience and perceptions of the actual implementation of their planned 3D instructional task as a part of the post-project qualitative interview. The 3-Dimensional Task Narrative was used for planning the students’ 3D Learning experience and the 3D CoRe was utilized to gain insight into the teachers’ thinking and knowledge about 3D Teaching related to their chosen Performance Expectation (Bertram, 2014). Whereas the post-instruction debrief and the post-project reflective interview were utilized to gain insight into the actual practice of each teacher related to the 3D CoRe and 3-Dimensional Task Narrative. These data will be presented and discussed as PaP-eRs in a condensed manor for each participant with callout boxes to highlight examples of implementation of 3D Learning in the classroom (Bertram, 2014; Loughran, Berry, & Mulhall, 2012). In some instances, certain sections of a teacher response have been highlighted as a specific example related to the appropriate callout box.

Irene's PaP-eR. Irene planned and implemented her 3D instructional task in a fourth-grade classroom and focused on 4-ESS2-1: Plan and conduct investigations of the effects of water, ice, wind, and vegetation on the relative rate of weathering and erosion. Irene's PaP-eR is shown below in Table 14.

Table 14

Irene's PaP-eR

Interviewer: Talk me through the actual day that you did it, from beginning to end. How did it go?

Irene: Yeah, they were very excited when they came in and saw all this stuff you know of course. Are we going to get to eat it? What's this for? All of that stuff. And so, you know I got them to quiet down. They looked at the picture. You know, and I think they had to write what they saw. In the pictures, what did they think was happening? What were some things that they saw? So, I think they, actually I'm remembering, and I think they had to write that down. And so, when that was over I gave them instruction on what they were going to do to construct their experiments. And all they were supposed to do is just construct the experiment and observe what was happening, what was going on. They had sugar cubes, in a dish, and they were stacked up so high, so many. And then the graham cracker was laying on top and they had to pour the water in the middle of the graham cracker. Maybe the first student poured, maybe the first time they poured, each student poured one drop. And what was so surprising is that I thought some would be not interested, not engaged. I thought you know how would I handle that? What would I do if there were some that just weren't interested? But there was not a single student that was not interested. Which, was incredible. And so, as I walked around, and I saw other groups and they were making their notes, drawing their pictures. That's when they started coming up with their scientific, with the words you know. What's underneath is eroding or the top of the cookie or the top of the graham cracker is becoming soaked, the water is absorbing. They were just really throwing out those terms and they were writing it down. And still all through it they never disengaged. At that point a student said the sugar "eroded" underneath which made the graham cracker fall through and created the hole. You know that's one of those things that you wish as a teacher you had directed but it was something they got on their own. So, they took my lesson even to a higher level than I expected.

> Here Irene discusses how the lesson engaged students in investigating the phenomenon through guided inquiry. She points out that the students were excited about the prospect of getting to investigate and collect data about the phenomenon for themselves. This indicates that this is not a normal experience for these students. Irene is surprised at how engaged the students are and how much knowledge this activity was able to draw out of the students. The students exceeded her expectations.

Interviewer: In what ways did the design of the task encourage students to generate ideas, questions, evidence, or conclusions?

Irene: In this task the sink hole video showing the phenomenon was placed after the phenomenon investigation. The students were given the opportunity to create their own knowledge and it generated a lot of conversation and questions. Showing the video first would have totally given it away and taken away their curiosity thus curtailing the students' opportunity to use their higher order thinking skills. This allowed the students to really focus in on what they were observing. Students used scientific vocabulary as they conversed with their team. Vocab examples: contracting, expanding, melting, dissolving, absorbing, liquid, particles

> Here Irene is strategic in the structure of the learning experience. She allowed the students to experience the phenomenon and draw their own conclusions before showing them what the phenomenon looked like. This provided the opportunity for students to construct knowledge for themselves.

Interviewer: What elements of the task best promoted student engagement?

Irene: The design of the sequence of the investigation. The fact that it was hands-on. The hands-on exploration with the graham crackers and the sugar cubes that simulated a sinkhole. The video of trees being pulled into a sinkhole, because they could not tell that the trees were being pulled into a sinkhole this left them with more to think about. Other videos of more sinkholes that were very obvious to the students.

> Here Irene reflects on the experience and her perceptions that the student centered, hands-on nature of the investigation lead to the success of students understanding the concept and being able to apply it to a real life scenario.

Interviewer: Is the phenomenon appropriate for addressing the grade level disciplinary core idea? Why or why not?

Irene: Yes, because dissolving matter and erosion of the layers beneath the crust creates sinkholes.

> Here Irene is able to make the connection between the focus DCI and the phenomenon.

Interviewer: What scientific and engineering practices seemed to contribute to the students' ability to construct explanations for the phenomenon and/or DCIs?

Irene: #1- Asking questions #2- Developing and using models- the students created a model of a sinkhole. This was part of the exploration and was not identified as a sinkhole until later in the discussion. This could possibly be labeled on their drawings in a follow-up lesson. #4 - Analyze and interpreting data- Students analyzed what was happening in their experiment after each session of dropping the water droplets. #6- Constructing Explanations- Students started to construct explanations. This may need to be elaborated on in the next lesson. Students revised their thinking as the lesson progressed. #8- Obtain, evaluating, and communicating information- Students were evaluating and revising their thinking as more information was gained.

> Here Irene is able to both identify the SEPs that her students engaged in as well and to describe the specific way in which the students utilized the SEPs during the investigation. This shows that Irene herself has an understanding of the SEPs.

Interviewer: Were students successful in using evidence to construct well-reasoned and accurate explanations? Why or why not?

Irene: Students discussed their ideas for how a sinkhole is made with their team and then shared with the whole class. Possibly using a CER would help them construct their knowledge. This could help them get their thoughts in writing and be accountable for their claim and reasoning.

> Here Irene discussed how her students were able to communicate their understanding of the DCI concept. She also reflects on how this could be refined using a CER structure so that students are prompted develop their ability to communicate scientific ideas.

Interviewer: In what ways did students use crosscutting concepts in constructing their explanations?

Irene: Cause and effect –The students saw that the more drops of water they put on their model the hole got deeper.

> Here Irene was able to identify how the targeted CCC was utilized by the students during the investigation.

Interviewer: Were all three dimensions successfully integrated into the task as expected? How did this occur?

Irene: Yes (did not elaborate)

Interviewer: In what ways did the phenomenon drive the instruction?

Irene: The phenomenon investigation drove the lesson until the sinkhole video was shown. Students then were asked to compare and infer how the investigation related to the photos and clips of sinkholes. The phenomenon was used to engage the students to ask more questions and led the students to ask, "Can we lift up the graham cracker and see what is underneath?"

> Here Irene reflected on the role of the phenomenon in the investigation and how using a phenomenon drove the students to ask questions, investigate, and collect evidence.

Interviewer: What is needed to modify or improve this task if you taught it again?

Irene: Have the students lift up the graham cracker before showing the sinkhole photos. Students can then name what they see. Possibly during a later lesson, compare the graham cracker and the water drops to nonporous surfaces. Clarify the difference between quicksand and a sinkhole. Compare the sugar cube to something that is not porous to show that some objects will not soak up water, dissolve, water can't run through or around it. (May actually use sand or granite and keep the graham crackers as the earth's crust). Use only water the first time and the vinegar could be used as a possible relationship to acid rain. We discussed that this lesson didn't focus on acid rain. Possible do one with water and one with vinegar and look at the difference. Use a (CER) Claims, Evidence, Reasoning as an opportunity for the students to explain their reasoning and evidence.

> Here Irene reflects on the learning experience and how improvements could help students to make connections to other ideas related to the DCI concept.

Interviewer: What have you learned from using this instructional task that will help you in teaching future concepts?

Irene: I loved the students' reactions and I thought it was fun to teach this way. The students can feel the enthusiasm of the teacher and were totally engaged. I usually don't have a full class, but I am thinking about how this would work for my special education classes. I think the format of the lesson plan helps us to plan a well thought out flow to the lesson. Teaching this way is very similar to the way I normally teach. I start my lessons out with an active investigation, but I now find myself thinking more about the steps and the sequence of the lesson. The process of using a phenomenon is so engaging for the students and I love teaching this way. Our current science curriculum does not lend itself to this format of a lesson. The curriculum doesn't give us few investigations to do with our students.

> Here Irene reflects on how engaged her students were during the investigation and how this made teaching "fun". She also pointed out how her regular curriculum is not conducive to this type of student learning.

Kara's PaP-eR. Kara planned and implemented her 3D instructional task in a third-grade classroom and focused on 3-LS4-2: Use evidence to construct an explanation for how the variations in characteristics among individuals of the same species may provide advantages in surviving and reproducing. Kara's PaP-eR is shown below in Table 15.

Table 15

Kara's PaP-eR

Interviewer: If you would just talk me through the whole lesson.

Kara: It was a lot better than I thought it would be. I thought I was going to have ten minutes and be done and the kids are going be totally bored. And I thought you know what am I going to do with the other 30 minutes because, oh my gosh you know, I've got this much time and I didn't think it would go and be as effective, and the kids would do as much writing and communicating their learning in their thoughts as they did. So, when we started out I was kind of nervous thinking they're going to just think it's blow off and not a thing to pay attention to. So, we started off reading books about each type and comparing and contrasting the two books we did two fiction books and two nonfiction books about both types of bears. And then after we did that I had them do a diagram to compare and contrast both. Because at that time the reading skill we were working on a lot was compare and contrast obviously. Then we shifted into to discussing the cause and effect, what caused this bear, what would happen? What would the effect be if something happened? If it's food source went away? If they lost their environment? And the kids even went down to as far as wanting to discuss how many babies each one had and what they how long it took them to come out of the dens and different things. So, the kids had a desire to go farther and the kids had desire to do more. So, I ended up doing a lot more with the research aspect of it than I intended to. Just because the kids had the desire to move forward and they wanted to find out more about each. And then they wanted to throw in different kinds of bears. Can we can we find out about the sun bear; can we find out about this bear. And so, I ended up letting them find information about different types of bears. That started with just the two, the grizzly and the polar bear. Based on that I mean they had a huge understanding, and huge learning, and able to communicate everything that they found, and they wanted to tell the other classes about it. So, I let them.

Here Kara talked about how the student engagement and learning far exceeded her expectations. She discussed how presenting the phenomenon to the students caused them to generate lots of questions and caused the students to investigate the concept at a much deeper level than she had planned.

Interviewer: In what ways did the design of the task encourage students to generate ideas, questions, evidence, or conclusions?

Kara: The description part at the beginning was useful to tie in what the students did throughout the instructional task. This instructional task was used to follow up some other activities that we had done in the past.

Here Kara discussed how she was able to integrate this learning experience into what her students had previously been learning about.

Interviewer: What elements of the task best promoted student engagement?

Kara: I liked that they knew and could apply the words in a new context correctly.

Here Kara described how her students were able to apply the academic vocabulary associated with the DCI concept.

Interviewer: Is the phenomenon appropriate for addressing the grade level disciplinary core idea? Why or why not?

Kara: Yes, it was things that we had discussed about animals, whether predator or prey, and it showed them more ways that the bears find food besides hunting. Sometimes they scavenge. It went with things that we had done in the past and let us expand on them.

Here Kara talked about how she was able to integrate this phenomenon investigation with other things her students have been learning.

Interviewer: What scientific and engineering practices seemed to contribute to the students' ability to construct explanations for the phenomenon and/or DCIs?

Kara: They asked questions about where the bears live and what their characteristics were, developed and used models with their Venn diagrams, analyzed and interpreted qualitative data, constructed explanations for how their bears survived and lived, they also obtained and evaluated and communicated information. I think that #8 was most impactful because through communicating the information they were tying everything together.

> Here Kara was able to communicate how students engaged in specific SEPs throughout the phenomenon investigation.

Interviewer: Were students successful in using evidence to construct well-reasoned and accurate explanations? Why or why not?

Kara: Yes (did not elaborate)

Interviewer: In what ways did students use crosscutting concepts in constructing their explanations?

Kara: Cause and effect in relation to the environments that the bears lived in and how they lived in their environment, Quantity in relation to how much the bears need to eat each day to prepare for hibernation, structure and function when describing the features of the bears.

> Here Kara was able to identify the targeted CCCs and describe how students utilized this thinking in making sense of the phenomenon.

Interviewer: Were all three dimensions successfully integrated into the task as expected? How did this occur?

Kara: I feel that the crosscutting concepts were not equally integrated with the other two dimensions. I feel that there was more I could have done with the CCCs.

> Here Kara was able to reflect on how well each of the three dimensions were utilized in relation to each other. This indicates her understanding of the three dimensions.

Interviewer: In what ways did the phenomenon drive the instruction?

Kara: It let them compare and contrast the differences and similarities of both bears. It also let us get into discussions about the environments and the animals that live in those environments and habitats. We did a lot of noticing and comparing with what we can see and observe.

> Here Kara emphasized that the phenomenon provided the students the opportunity to develop and practice making observations and making inferences.

Interviewer: What is needed to modify or improve this task if you taught it again?

Kara: I would make sure to read the bear story books the day before instead of the week before. I would also have the kids use iPads to look up information for themselves. They could also draw and label the physical features of the bears, maybe do a Prezi or some other presentation.

Here Kara describes strategies that would shift ownership of the learning more to the students and help them practice developing models.

Interviewer: What have you learned from using this instructional task that will help you in teaching future concepts?

Kara: The students seem to grasp the concepts better and retain what they are learning and hearing longer, because they are doing so much with it. They are seeing where it is in their everyday life and where it is valuable to them. I like how we can tie in with everything else we've done through the year, reading and language and every other subject (e.g. English, Math, Social Studies, etc.). It is much easier to integrate the subjects with this format than it would be than telling them to go to page three in the book.

I like shifting my way of thinking and teaching to more student expression and experiential learning. It is not about giving them information but having them explore the concept on their own and investigate it and then being able to come to their own conclusions about things. Kind of being more of a facilitator than an instructor.

Here Kara perceives that the students are experiencing deeper, longer lasting learning when they construct knowledge for themselves compared to direct instruction or relying on the textbook. She indicates that this is a shift in the way that she thinks about teaching. Kara also discussed how this style of teaching made it much easier for her to integrate other subjects into the same student learning experience.

Diana's PaP-eR. Diana planned and implemented her 3D instructional task in a sixth-grade classroom and focused on MS-LS2-1: Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem. Diana's PaP-eR is shown in Table 16 below.

Table 16

Diana's PaP-eR

Interviewer: If you would, talk me through the lesson.

Diana : I have this big table that I laid out. Big pompoms, little pompoms, sunflower seeds, broken toothpicks, beads, and some other little bitty things. And then that was considered the food. The beaks were, one student had tweezers, one student had a spoon, one student had a binder clip. There were six different ones, I don't remember what the other three were. Oh, forks, no, tongs, clips, spoons, forks. They had 30 seconds, and they had to stay in their area. They couldn't like reach over and get other people's food and they had to pick up as much food as they could with their utensils. And you could do it as a whole group.

> Here Diana shows that she is choosing a learning experience that is focused on students experiencing the selected concept and collecting data that students can use as they construct explanations for the phenomenon utilized to drive the student learning experience.

Interviewer: Before they did the investigation. How did you start the lesson out?

Diana : I started out with a video of the Galapagos and Charles Darwin and his five weeks that he spent on the Galapagos and all of his research that he did. Not necessarily just the beaks of the finches, but the Penguins and the tortoises and all of the other animals.

> Here Diana chose a phenomenon that relates directly to the DCI and PE chosen for this grade level.

Interviewer: How did you transition?

Diana : Well we went from very generic of all of the animals, to specifically just the finches. Because it started out as one species and evolved into 13 different species. And so, I showed a picture of 13 different beaks and what each type of beak foraged on. Whether it was seeds or berries or nuts or whatever. And then we started the activity.

> Here Diana describes in more detail the phenomenon that will drive the learning experience. It directly relates to the DCI and PE, however may not be relevant to her specific students.

Interviewer: How did your students respond to that? Did they have any questions? Did that cause interest or anything?

Diana : Oh yeah, they loved it. They wanted they wanted to know more about it. So, then we researched some more about two scientists that are there, that go for five months out of the year and they research, they watch the finches for five months. And they determine you know basically the same exact stuff that Darwin did but more in depth.

> Here Diana perceived that her students were engaged during the learning experience. She saw that her students were able to generate interest and questions centered on the DCI.

Interviewer: So, after the students gathered their data. So, they eat the food and they gather the data. What did you do from that point?

Diana : Then we talked about all of the data and we wanted to know, you know, what were... We analyzed the data with, which bird would survive no matter what seed was, you know, that he could eat anything. And it was the one that used the spoon. Because they could pick up the most food. And which finch would you be able to, would you think would die out the first or the fastest. And if this food wasn't available what would happen to X Y and Z? So, we talked about it mostly as a class and very informal. I had a data sheet and then I had some questions and it was the questions that, So, we talked about the data and then we answered the same questions and then I had him write it down on a worksheet, basically. So, they knew the information and we talked about it but then they had to physically write it down.

> Here Diana describes her students engaged in the SEP analyzing and interpreting data and making inferences from the data.

Interviewer: In what ways did the design of the task encourage students to generate ideas, questions, evidence, or conclusions?

Diana: The phenomenon is the beginning of a video talking about how there are different types of finches in the Galapagos Islands. A wall map was also used to help tell and illustrate the story of how scientist discovered the different finches on the islands. Students ask questions about this. Another way to present the phenomenon without using a video might be to show pictures or drawings of the different finches and tell the story of how scientists discovered them. Then ask the students how this might have happened. Students use different tools to gather "food" and collect class data on the types of food related to each tool. They analyze the data through a series of guiding questions. Students were asked to make connections between the evidence they gathered and the beaks of the finches.

> Here Diana provides specific examples of utilizing phenomena in a way that causes students to generate questions. She also is very reflective on how she could better leverage the phenomenon in the learning experience. Diana provides examples of how she went about utilizing the SEPs to facilitate students in making connections between their data and the targeted DCI.

Interviewer: What elements of the task best promoted student engagement?

Diana: The foraging activity was fun and interesting to the students. The guided questions from the class data and having students keep their own chart of the class data kept them focused during questioning and they were very interested in thinking about differences and similarities in the data. Providing the vocabulary during the activity instead of at the beginning and then having them use that vocabulary in their final explanation.

> Here Diana was able to reflect on the idea of letting the students experience and develop the concept first before providing the academic vocabulary related to the concept.

Interviewer: Is the phenomenon appropriate for addressing the grade level disciplinary core idea? Why or why not?

Diana: Yes – the DCI is directly related to this activity and it was not too hard or too easy for the students. It seemed to hold their attention.

> Here Diana shows an understanding of the DCI and how the activity her students engaged in related to the DCI concept. However, she does not directly address the phenomenon or the other two dimensions.

Interviewer: What scientific and engineering practices seemed to contribute to the students' ability to construct explanations for the phenomenon and/or DCIs?

Diana: Constructing explanations, designing solutions, asking questions, carry out investigation (not plan), analyzing and interpreting data – this is guided inquiry.

> Here, through reflection, Diana is able to identify the SEPs, but does not go beyond identification.

Interviewer: Were students successful in using evidence to construct well-reasoned and accurate explanations? Why or why not?

Diana: They used the data they gathered to make connections to the adaptation by the bird species to foods on different island environments. They utilized structure and function, patterns, cause and effect, system thinking, and stability and change were used as themes for discussing results. It is helpful to explicitly use these words with students, so they see that the activity relates to major scientific processes and methods of thinking.

> Here Diana perceived that her students were able to make clear connections between their experience and the intended concept through being able to utilize the CCCs to explicitly facilitate student thinking around the DCI concept.

Interviewer: Were all three dimensions successfully integrated into the task as expected? How did this occur?

Diana: Yes, students used all the above practices to help them explain the phenomenon of the finches.

> Here Diana indicates that the SEPs, CCCs, and DCIs were integrated.

Interviewer: In what ways did the phenomenon drive the instruction?

Diana: The phenomenon captures the attention and curiosity of the students. It gives them something to explain using the evidence gathered in the activity. They were invested in the data because they gathered it themselves. The data allowed them to draw appropriate conclusions about the phenomenon.

> Here Diana reflects on how shifting her teaching to allow her students to gather and analyze data for themselves to answer their questions about the driving phenomenon gives students ownership of their learning.

Interviewer: What is needed to modify or improve this task if you taught it again?

Diana: Perhaps cookie sheets or trays at each table with the same objects on them would allow all students an opportunity to "forage" instead of just a few. Perhaps each table could have a different tool and all of the students have their own tool. This would increase the numbers on the data. Change the wording in the activity sheet from "seed" to "food."

> Here Diana is able to reflect on how she could better facilitate the experience so that students are more engaged in analyzing and interpreting data in ways that they can make sense of the concept and apply it to the phenomenon.

Interviewer: What have you learned from using this instructional task that will help you in teaching future concepts?

Diana: I struggled a bit with how to present the phenomenon and it is helpful to get perspectives and suggestions from other people.

Here Diana reflects on how collaboration with colleagues is helpful to her practice.

Jane's PaP-eR. Jane planned and implemented her 3D instructional task in a sixth-grade classroom and focused on MS-LS2-4: Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations. Jane's PaP-eR is shown below in Table 17.

Table 17

Jane's PaP-eR

Interviewer: If you would talk me through how the lesson went from start to finish?

Jane: I had planned on coming in and we do it. I picked five volunteers and I coached them really fast. And then I have them show me the succession play. Then I had individual cards. Before we did that, they had a phenomenon. We talked about the phenomenon. And I was really surprised and excited. This is my first time really trying to implement this and I showed the picture of the phenomena and the amount of them telling me, getting excited about the possible explanations for the phenomenon and just really talking. It was more student led than I have ever let it be. And it was one of the best days ever because they got so excited about why the phenomenon occurred and so we did. So, my plan was the phenomenon, then the play, then the cards, then a quick little slide show and show and making sure they did it and then we all stood up and we kind of reviewed what we had learned that day.

Here Jane discussed how excited she was about the engagement and discussion that was elicited from her students when using a phenomenon to drive the student learning experience.

Interviewer: What was what was the phenomenon?

Jane: It was just it was just one. I think it was just one tree growing in the middle like a Mexican city that there was nothing else and everything was desert and there was just one tree there. And so, the questions were kind of like how to get there? What caused this? What? It was like growing through the pavement. So how does it grow through the pavement? And so, so they generated a bunch of questions to. I was excited about that. And then they, some of them crazy answers and then some of them are really smart.

> Here Jane discussed how using a phenomenon caused her students to generate their own questions and to draw their interests into the phenomenon investigation.

Interviewer: In what ways did the design of the task encourage students to generate ideas, questions, evidence, or conclusions?

Jane: The phenomenon was used to get kids asking questions because it is a relatively unusual occurrence.

> Here Jane talks about her perception regarding how students are not normally this engaged in asking their own questions and the role of the phenomenon in engaging her students.

Interviewer: What elements of the task best promoted student engagement?

Jane: The phenomena - evidence of engagement is the great questions students were asking about the picture of the plant in the middle of the concrete and the explanations they were putting forth and rebutting. The card sort got great conversation and discussion from the students. Succession play - found themselves in the videos they saw later, indicating they were engaged and got something from the activity. The scenario about what would happen if your school was vacated was also engaging. Drawing the pictures helped focus them a bit as well.

> Here Jane talks about how collaborative her students were during the phenomenon investigation co-constructing and critiquing explanations throughout the learning experience. Jane describes some of the strategies used to engage students in investigating the phenomenon.

Interviewer: Is the phenomenon appropriate for addressing the grade level disciplinary core idea? Why or why not?

Jane: Yes - students were interested and engaged into the task right away. Relates to the DCI about physical or biological components affecting populations - could also work with changes in ecosystems.

> Here Jane communicates here understanding of the DCI and how the phenomenon she chose to drive the learning related to the DCI concept.

Interviewer: What scientific and engineering practices seemed to contribute to the students' ability to construct explanations for the phenomenon and/or DCIs?

Jane: Asking questions, using models (the play), constructing explanations, arguing from evidence, and obtaining information. All of these practices are being done while students try to come up with an explanation for why the plant is growing in an area of concrete.

> Here Jane is shows her understanding of the SEPs and how students engaged in the SEPs during the learning experience.

Interviewer: Were students successful in using evidence to construct well-reasoned and accurate explanations? Why or why not?

Jane: They were having varying levels of success, but they eventually got to the main ideas through collaborative sense-making guided by the teacher.

Here Jane discussed the importance of student collaboration in the sensemaking process.

Interviewer: In what ways did students use crosscutting concepts in constructing their explanations?

Jane: Patterns and cause and effect were used in the card sort and in trying to generate explanations.

Here Jane conveyed her understanding of the targeted CCC and the lesson strategy that caused students to utilize thinking about patterns and cause and effect.

Interviewer: Were all three dimensions successfully integrated into the task as expected? How did this occur?

Jane: Yes (did not elaborate)

Interviewer: In what ways did the phenomenon drive the instruction?

Jane: It was engaging for the students. It was something you can explain with information you gather.

Here Jane reiterated how the phenomenon engaged students in exploring the phenomenon and constructing their own explanations about the phenomenon.

Interviewer: What is needed to modify or improve this task if you teach it again?

Jane: Instead of pictures, an outdoor area where different forms of succession are evident (tornado?) or get pictures from the internet of places where it has occurred - Mt. St. Helens was suggested (time becomes an issue for trying to narrow down options of what to use, especially if you only have about an hour for class). In the card sort - the pictures might work better if they were all from the same distance or perspectives (easier to compare). Cut the pictures away from the descriptions (card sort) and make them part of the sorting task or have them order the pictures first and then try to match the vocabulary on the other cards with the pictures - this would add a bit of structure to the activity, so they might not be as confused. This phenomenon would also work for teaching about changes in ecosystems. Lion King picture on its own would be a good phenomenon too. Be explicit in using the word "model" when they do the play.

Here Jane reflects on how the strategies used in the lesson could be improved to provide scaffolding for the students in making sense of the phenomenon.

Interviewer: What have you learned from using this instructional task that will help you in teaching future concepts?

Jane: Teaching this way has resulted in more science conversation from students because you are engaging them more and the conversation you get is amazing. Action research experiment - providing different structures for the card sort in different hours - one class was told the first card in the series and the other class wasn't. There were different responses - the second group of students struggled more but may have eventually understood the concept of succession better than the first group because they had to struggle with it more. Doing the succession play was fun but a bit chaotic. When you teach the concept of succession before the play (like Jane has done it before) there is less silliness but maybe not as much learning. The tradeoff for doing the activity first and the concept last can be a little bit of chaos. Teachers just need to decide when it is worth it and when it isn't. Sequencing activities is part of the art of teaching - you have to experiment to see what works best. In general, it is better to do investigation first and vocabulary last.

Here Jane talked about how amazing it was from the teacher perspective to have students actively engaged in collaborative discussion and sensemaking. Jane also discussed the idea of changing her teaching so that students are creating meaning through first hand investigation before introducing academic vocabulary. This indicates she is shifting from a teacher centered mode to a student-centered mode on instruction.

Miranda's PaP-eR. Miranda planned and implemented her 3D instructional task in a tenth-grade Biology class and focused on HS-LS3-1: Ask question to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring. Miranda's PaP-eR is shown below in Table 18.

Table 18

Miranda's PaP-eR

Interviewer: If you would, talk me through the day the lesson.

Miranda: We first started off showing them the large picture with a whole bunch of mutations and they seemed very surprised with all the mutations. And at that point I realized that was way too much. Maybe one or two mutations because they kind of went off a little bit then from where I wanted them to be. We did the "I notice I wonder" strategy and then we had them compare. We wrote it on the board and then that's when I started the telephone game where they had to come up with sentences. I handed out prepared phrases on cards and they had to code them and then pass them to the next group. So that seemed to go ok. They were a little confused because this is not what they normally do in regular classes. And so, they coded their words. And then when they got a new one passed to them they had to decode it and write what they thought the sentence said and then we ended up sharing it with the class. Then I think we watched the pocket mice video. They continue to talk about the rock pocket mice for weeks afterwards. And when you get different lessons we go back to remember the rock pocket mice.

> Here Miranda discussed the sequence of the phenomenon investigation and described how this mode of instruction was different than what students normally experience.

Interviewer: In what ways did the design of the task encourage students to generate ideas, questions, evidence, or conclusions?

Miranda: We started with the "I notice/I wonder" strategy. I was hoping that would generate some questions.

> Here Miranda describes a strategy she utilized to help her students engage with the phenomenon.

Interviewer: What elements of the task best promoted student engagement?

Miranda: I think that the coding was the most engaging for the students. All the students seemed to be engaged in this portion of the task.

> Here Miranda talked about how one aspect of the instructional task engages students as they were actively modeling the concept.

Interviewer: Is the phenomenon appropriate for addressing the grade level disciplinary core idea? Why or why not?

Miranda: Yes, however I will probably use fewer images next time.

> Here Miranda reflects on how she can refine how the anchor phenomenon could be presented to students to better focus their investigation.

Interviewer: What scientific and engineering practices seemed to contribute to the students' ability to construct explanations for the phenomenon and/or DCIs?

Miranda: #1 Asking questions, #2 Constructing and using a model, #4 Analyzing and interpreting data.

> Here Miranda was able to identify the SEPs that students engaged in during the phenomenon investigation but does not elaborate on how the student used the SEPs.

Interviewer: Were students successful in using evidence to construct well-reasoned and accurate explanations? Why or why not?

Miranda: No, I might have one or two students that could construct and explanation, but they are not there yet.

> Here Miranda reflects not some of her students were able to construct explanations for the phenomenon, but other students were not successful in explaining the phenomenon.

Interviewer: In what ways did students use crosscutting concepts in constructing their explanations?

Miranda: #1 Patterns, #2 Cause and Effect, #6 Structure and Function.

> Here Miranda was able to identify the CCCs students utilized, but did not elaborate on how students utilized this type of thinking.

Interviewer: Were all three dimensions successfully integrated into the task as expected? How did this occur?

Miranda: Yes, but I could have integrated more of the DCI.

> Here Miranda was reflective on her instruction and how she could better integrate all three dimensions.

Interviewer: In what ways did the phenomenon drive the instruction?

Miranda: We kept tying it back to mutations as discussed with the phenomenon.

> Here Miranda described how the phenomenon continued to drive the students' learning throughout the phenomenon investigation.

Interviewer: What is needed to modify or improve this task?

Miranda: Modify the Phenomenon to use just one image or images of parents and offspring to reduce off task questions. Smoother transitions between the different components of the task. Make the connection from the coding activity to transcription and translation more explicit.

> Here Miranda was able to reflect on how she could revise the task to better focus her students' investigation of the DCI concept and anchor phenomenon.

Interviewer: What have you learned from using this instructional task that will help you in teaching future concepts?

Miranda: I am trying to use phenomena more in my instruction and have been using the 3D language. With this approach we are getting the student to think for themselves more.

> Here Miranda perceived that with 3D learning students are able to take the central role in constructing knowledge.

Jill's PaP-eR. Jill planned and implemented her 3D instructional task in a ninth and tenth-grade Biology class and focused on HS-LS1-3: Plan and conduct an investigation to provide evidence of the importance of maintaining homeostasis in living organisms. Jill's PaP-eR is shown below in Table 19.

Table 19

Jill's PaP-eR

Interviewer: If you would just talk through the lesson.

Jill: With the phenomenon, with phototropism the majority of the first questions that kids said was that they observed the pot was knocked over. It took them a while to realize hey this stem is actually bent and now it's not growing straight. Not that it was growing this way. OK, but what's making it? It was really a struggle to get them toward that thinking of what's making them curve. And then I had one group specifically that I remember, their key thought was increased photosynthesis. And that was all they were stuck on. They could not move toward increasing the chains of photosynthesis for sunlight or to reduce temperature. It was a roadblock. Every direction that they went. I did try to get them to get it and I don't know if they ever got it.

> Here Jill discussed how difficult it was for her students to change their mindset from trying to provide the "right" answer and not making observations to generating their own questions and coming up with their own explanations.

Interviewer: So, from the phenomenon what happened after that?

Jill: Well they did research to find explanations as far as why they are bending to the light source. I did allow them to conduct experiments to be a be able to test that idea and several of them got it actually. As far as understanding the whole concept, when they provided me with additional pictures. As far as examples that would actually explain what they were identifying. Most of them could find additional pictures, a few of them were a little confused. But, once we came together and explained all of it as a class. They were like, oh that's what that was. OK, I got you. After the research everything they could to actually identify a difference between positive and negative reactions with gravity and realize that even if it's negative or positive. Gravity could still be positive or negative tropism at the same time.

> Here Jill talked about how providing the opportunity for her students to investigate the phenomenon for themselves and construct their own explanations they were able to come together and as a group collaboratively come to an understanding of the DCI concept in the context of tropism.

Interviewer: Thinking about some of the struggles you had with you with some your students. How did you go about dealing with those?

Jill: I think it was just more questioning. Just providing questions in order to get them, you know, thinking of other factors. We know its photosynthesis. Plants need photosynthesis but, what if they have too much light? What if they have obstructions? Can they actually get to the light? And get to that route?

> Here Jill described how she used guiding questions to facilitate her students making sense of the phenomenon. This is a shift from direct instruction.

Interviewer: In what ways did the design of the task encourage students to generate ideas, questions, evidence, or conclusions?

Jill: The task forced them to generate an investigation to test their ideas which requires them to generate questions and evidence. The students had to reverse engineer an investigation, they were given the results and had to design an investigation to match those results. Toward the end of the task they had to find related examples.

> Here Jill discussed how the structure of the phenomenon investigation was intentional about forcing students to generate their own questions and resulted in them planning and conducting their own investigations to answer their questions.

Interviewer: What elements of the task best promoted student engagement?

Jill: Student ownership, they worked in small groups. They were allowed to design their own investigation. They were not just limited to me just telling them what tropism is. They were allowed to construct the idea themselves.

> Here Jill reflected on how the nature of the task, using a phenomenon to drive the learning, along with student collaboration helped students become invested in owning the learning and knowledge they constructed.

Interviewer: Is the phenomenon appropriate for addressing the grade level disciplinary core idea? Why or why not?

Jill: The Phenomenon was tropism, both positive and negative. Yes, I think so because the students had not experienced it before. The students had to work for the explanation.

> Here Jill was able to make a solid connection between the targeted DCI and the phenomenon she selected for the students to investigate.

Interviewer: What scientific and engineering practices seemed to contribute to the students' ability to construct explanations for the phenomenon and/or DCIs?

Jill: Constructing explanations, Planning investigations, Asking questions, Engaging in arguments from evidence (argue how their examples relate to tropism), obtaining and evaluating and communicating information.

> Here Jill was able to identify the SEPs that the students engaged in during the phenomenon investigation.

Interviewer: Were students successful in using evidence to construct well-reasoned and accurate explanations? Why or why not?

Jill: Yes, the majority of the students were able to. Some were stuck on it increased the rate of photosynthesis and didn't go further in their research to find a more accurate explanation.

> Here Jill reiterated the difficulty some of her students had in shifting their learning to a student-centered context.

Interviewer: In what ways did students use crosscutting concepts in constructing their explanations?

Jill: Cause and effect, structure and function, stability and change.

Here Jill identified the targeted CCCs but did not elaborate on how students utilized these ways of thinking.

Interviewer: Were all three dimensions successfully integrated into the task as expected? How did this occur?

Jill: For the most part. This occurred when the students were identifying different examples of tropism.

Interviewer: In what ways did the phenomenon drive the instruction?

Jill: Yes, it was central to the task. They had to keep coming back to the idea of tropism. They designed investigations to test types of tropism. They had to find other examples of tropism and explain what was occurring.

Here Jill emphasized the importance of the phenomenon in driving the students to explore the DCI concept through planning and conducting an investigation and relating the DCI concept to other real-life examples.

Interviewer: What is needed to modify or improve this task?

Jill: I need to have more group level conversations to guide some of those students who need more help. Could have a list of possible websites for those students who might need them.
I want to be able to adjust it to my higher-level kids and let them take it to a higher level. Some of the students were confusing the different types of tropism.

Here Jill talks about possible strategies she could implement to improve the learning experience so that students are more successful in their investigation of the phenomenon.

Interviewer: What have you learned from using this instructional task that will help you in teaching future concepts?

Jill: I have a lot to learn. Giving them that freedom and allowing them to use their observations and their predictions to drive where they were going, because there were multiple answers here. I'm not used to that. I'm more used to here is the information, let's test, but this is totally different. I was a little uncomfortable at first, are they going to get it. I think that this will stick with the students longer. I bought up a picture of another type of tropism at the end and nearly all the students could explain it because they discovered the concept for themselves.

Here Jill talks about how this mode of teaching is different than her typical mode of teaching. However, she reflected on how using phenomena to drive the student learning would result in deeper longer lasting understanding because the students constructed knowledge about the concept for themselves.

RQ4: Teachers' Experiences within Three-year 3D Learning Focused Professional Development Context Leading to Growth in Teachers' Understanding and Implementation of 3D Learning and Teaching

In order to answer RQ4, "What experiences within the first year of a three-year 3D Learning-focused professional development context can lead to growth in teachers' understanding and implementation of 3D Learning and Teaching?", participants took part in semi-structured interviews designed specifically to make these teachers reflect upon their experiences in the project and these that were most meaningful and had the most impact on their teaching practice. A series of open-ended questions were utilized to facilitate this reflection and draw upon the teachers' experiences. These interviews were transcribed and analyzed for emergent themes. Theme 2, Growth Support Structures, centered on the structures and resources that participants identified, either directly or indirectly, as having an effect on their growth in understanding and implementation of 3D Learning. Theme 2 is relevant to RQ4 and is discussed in the following section.

Theme 2: Growth support structures. Within the theme of growth support structures for the teachers, two sub-themes were evident (see Table 20 below). Sub-Theme One consisted of structures that were internal for the participants, and Sub-Theme Two consisted of structures that were external to the participants. Sub-Theme One, Internal Structures, are presented as opportunities in which the participants could engage. The Internal Structures sub-theme was composed of four components: opportunities for self-reflection or self-realization, opportunities to understand 3D standards (how to read them, what each dimension was [SEPs, CCCs, and DCIs], and how the three dimensions are integrated into instruction), opportunities for the teachers to be learners, and opportunities for teachers to be encouraged and develop a belief in self. Sub-Theme 2, External Structures, was composed of five components, 3D Instructional Model, 3D Instructional and Assessment Task Structures and

Table 20

Theme Two from Qualitative Analysis

Theme 2: Growth Support Structures		
Sub-Themes	**Codes**	**Description**
Internal Structures	Opportunities for Self-Reflection/Realization	Participants described moments during year one of the project in which they engaged in self-reflection regarding their instructional practices in light of 3D Learning.
	Opportunities to Understand 3D Standards (e.g. how to read, dimensions, integration)	Participants described moments in which they were given the opportunity to understand 3D standards, including how to read the standards, what each dimension entails, and how to integrate them into learning experiences for students.
	Opportunities for the Teacher to be the Learner	Participants described moments during year one of the project in which they were given the opportunity to experience 3D Learning first hand as a learner and then to reflect on these experiences from a teaching perspective.
	Opportunities for Encouragement and Belief in Self	Participants described moments when they were encouraged either through personal successes, from colleagues also in the project, or from project staff and how these opportunities allowed them to believe in themselves and their ability to carry out 3D Learning in their classrooms.

External Structures	3D Instructional/Assessment Task Model Structure and Instructional/Assessment Tasks Database	Participants described moments when planning and implementing 3D Learning were successful and easier to accomplish as a result of the 3D Learning model and/or Instructional & Assessment Task structure utilized in the project. Participants discussed that having access to the shared folder containing Instructional Tasks and Assessment Tasks created by other participants in the project and project staff provided examples and resources that made planning and implementing 3D Learning easier.
	Teaching Resources and Strategies	Participants discussed that experiencing and having access to strategies and project resources, such as resource books allowed them to successfully plan for and implement 3D Learning.
	Peer Collaboration	Participants described instances in which having the ability to collaborate with other teachers also transitioning toward utilizing 3D Learning and Teaching allowed them the opportunity to have community network of support as they planned and implemented 3D Learning.
	Project Staff	Participants described moments when project staff provided direct support to teachers when planning and implementing 3D Learning.

3D Instructional and Assessment Task Database, Resources and Strategies, Peer Collaboration, and Project Staff. This theme is discussed below, and related results are presented.

Results.

Internal Structures: Opportunities for Self-Reflection and Self Realization. Many of the participants discussed that through taking part in the project they realized things about their teaching and themselves as teachers. In reflecting on her content knowledge and pedagogical knowledge Irene stated,

> Realizing that I knew more than I thought I did. That maybe the refresher that I got there for content knowledge, you know. And while I'm not a high school science teacher by any means you know, my knowledge actually goes beyond what I thought it did in terms of helping my students.

Kara also mentioned reflecting on her awareness of her knowledge and how she thought about teaching,

> Going into it thinking I know enough where I can get by. This let me be able to see what I knew and then how I could go back and take it to kids and we could learn together. And doing that and then sitting down and going through the three dimensions and going through the lessons and going through all the standards. It helped me realize, you know, this possible to do even though it's not a tested in our grade. It's still possible to do this. It's still possible to get lots of learning.

Kara also spoke about her self-reflections in relation to other areas of her teaching. Kara was able to reflect on what was important to her as a teacher for her students,

> It made me go back and look at how I taught things more in depth. It made me go back and look at the skills that I taught and revisit why they were important and what was important about them.

Additionally, Kara talked about her realization about the importance of teaching science in all grade levels,

> Made me realize it needs to be taught in every grade level, not just in the upper grades. Every grade level needs to teach it [science]. It made me realize that even your kindergartners and first graders second graders can do science at their level and present and tell more of what they've learned than anybody ever thought.

Jane talked about how participation in the project helped her to see what she didn't know and as a result she was able to reflect on her own teaching practice,

> The CORPS project did change how I was teaching completely. Because honestly when my principal told me to sign up for this I thought I knew everything. I thought I knew what the standards where. I thought I knew how to implement them and how to teach them. And then I came in and I realize that I didn't even scratch the surface of what they were asking me to do. I thought I looked through and thumbed through and looked at my book and thought okay well I'll just teach this and not this. And I really was totally missing the mark and I didn't know what crosscutting concepts were. I didn't know I had to do engineering practices. I didn't know how to do it. I didn't know how to ask questions. I didn't know how to assess them. And then you got to be asking your students more questions and I didn't know how to ask these questions. I didn't know how to get that higher-level thinking. And then the last three years I've been able to feel comfortable and writing tasks and even writing

> assessments and feel like I am teaching what I'm supposed to be teaching.

Miranda also reflected on her knowledge as a teacher,

> I think going from just having the content knowledge to actually having content knowledge and knowing how students learn and putting it together. I had the content knowledge. I knew my area and what was relevant to them, you know, in rural areas. But just knowing, in my mind it was a new way of teaching, that it is more towards the way that people learn. You learn by doing things.

Jill's reflection was more focused directly on her motivation for participating in the project,

> I knew I needed that as far as learning how to do that [3D Learning and Teaching]. But, it's that hesitancy as far as learning something new. When you're far into your career do you really want to change? Do you want to be successful? Yes, yes you do.

Each of the participants expressed some level of self-reflection and/or self-realizations about their teaching. These reflections provided some insight into the participants motivation to grow in understanding and implementation of 3D Learning and Teaching.

Internal Structures: Opportunities to Understand 3D Standards. Another idea that participants expressed that had an impact on them through the project was the opportunity to gain a better understanding of the 3D standards. Each of the participants discussed different aspects of getting to experience the 3D standards and how this helped them develop a deeper understanding of what 3D Learning and Teaching was and how it looks in the classroom. Irene explained how knowing the standards shifted her focus on what she should be doing with her students,

> You know at first when we started going over the science standards and what had changed and how they were hit and miss and what we weren't doing any more as opposed to what we were going to be doing. You're focusing more on what can you do to engage the students.

Kara spoke specifically about how knowing the standards better made science as well as other subjects easier to implement in her classroom,

> It [project participation] made a lot easier to implement. It made it a lot easier to be able to use them [3D science standards]. It made a lot easier to understand them. It made it easier to write the lessons completely because it let me, not just have an objective and have to go what do they want because the new standards were pretty cut and dry once you knew how to read them. And once we got through how to read them and how what each piece stood for, it made it a lot easier to read those and then even to read the standards for the other subjects.

Diana had a similar experience,

> Then once you guys showed us, you know, how to do some of the instructional tasks. And how to desegregate the SEPs from the DCI guys and that performance expectations and what those all meant, in the standards book, and how it was set up. That explained it better to me to

where I could understand it to be able to build on those instructional tasks.

Jane spoke about how project participation went beyond simply understanding the 3D standards, but also provided examples of how the 3D standards could be implemented. She explained that these examples helped her develop a better understanding of 3D Learning and Teaching,

> Because it did make it easier seeing. Coming to CORPS wasn't just, this is the standard. That every time they had an example of how to teach it, how to make science fun, a lesson that we could actually do in our class.

Miranda talked about how going from learning how to read the 3D standards to using them to write 3D instructional tasks to implementing and getting feedback were helpful for her in developing her 3D Learning and Teaching,

> At first it was the original summer workshop where we learned how to read the standards and then actually writing a standard with our partner and teaching it and being observed and getting feedback I think because then you know we knew how to read the standards by then and we wrote a lesson. But at that point we weren't exactly really doing 3D and then getting the feedback of what we could do to make it better. I think really had the most impact.

Jill talked about how the 3D standards were intimidating for her at the beginning of the project, but how going through the project helped her have a better understanding of what 3D standards are and how the components relate to each other,

> I don't think they are as intimidating as what they were, as they first appear to be. Because you read the book and you look at the standards. There's three different colors. And you're like, what part am I supposed to even pay attention to? Once I went through the project it was a lot easier. Because this is it the SEPs so I know that's going to be there. But this is the only aspect I really need to focus on here. But yet this is how it relates to the crosscutting concepts. So, it was a lot less daunting.

Internal Structures: Opportunities for the Teacher to be the Learner. Another aspect that all of the selected participants identified as having an impact on their 3D Learning and Teaching was the opportunities during the project for each of them to take the place of the learner, the opportunity to experience 3D Learning for themselves from the student perspective. Irene spoke about the role of discovery in addition to having the opportunity to share ideas was powerful for her in developing her 3D Learning and Teaching,

> The "not teaching", the discovery [was influential]. You know, at times I know we were all very quiet and you know for a minute no one would answer a question because no one wanted to be wrong. Well as a teacher that puts you back in the student place and kind of makes you remember what your students feel like sitting there and you're wanting them to answer a question. And that, you know, people would answer a question and it wasn't, "you're wrong". It wasn't, "no that's not it". It was,

> "OK let's write that down", "let's put that up", "let's see where we go from here". And that was, that was teacher changing for me.

Kara talked about getting to do 3D Learning and to be able to experience the outcome of doing 3D Learning was important for her,

> And then as we started working through it and doing more of the stuff, with the other teachers and with the different instructors, and seeing what their outcomes were and what they wanted. And just seeing that it was okay to be excited about science.

Diana discussed how getting to experience 3D Learning lead to her excitement about 3D Learning and Teaching,

> This is how to use the resources. Because that was a big thing, is this is how you use the resource. And we're going to do one you know one of the activities. All the activities that you did. I mean it just totally got me hooked.

Jane discussed how seeing 3D Learning and Teaching modeled helped her develop an understanding of what 3D Learning and Teaching,

> The things I like the most and the things I've been most helpful have been the summer where they would do lab after lab and we would, we would do this instructional activity and explore this phenomenon and then we'd investigate it and then we talked about and then we go back and redo our model. And seeing that modeled over and over again. Here's your phenomenon, now you go with it. How has your thinking changed? That is what's totally changed my thinking. Because that's

> what I'm now teaching constantly. And before I never ever did that. They were helpful, and they made me understand what I was really supposed to be teaching. And then they modeled it over and over again for me. And then they taught me how to assess it.

Miranda talked about how the experience of engaging in 3D Learning and constructing 3D instructional tasks helped her grow her understanding of 3D Learning and Teaching,

> Experience I guess, doing it and doing it here, trying things out before I go to the classroom. At first it was just the like you actually telling us what this meant at first but then actually doing it within the workshops were actually doing lessons and creating lessons and being able to experience ourselves what our students are going to experience actually made it a lot easier.

Likewise, Jill expressed a similar experience,

> Just having the experience and the time dealing with it. I think probably going through some of the activities, with the workshops. Just being, as a learner. Having that experience as far as how to introduce it, how to lead the students into thinking, and then at this point, let's go ahead do an activity or research or investigation and then wrap it up come together. So, I think that probably helped more than if I was to read a book about it.

Each of the selected participants discussed how important it was for their development of their own understanding of 3D Learning and Teaching for them to be able to experience 3D Learning from a student perspective.

Internal Structures: Opportunities for Encouragement and Belief in Self. A few of the participants talked about how the process of participating in the project helped them be more confident in their teaching and helped them to believe that they could be successful in implementing 3D Learning and Teaching. Kara spoke about the confidence she gained through her participation in the project, “It makes me think, you know, can I take this idea, this concept that I have to teach and turned into something that I want to teach.” Diana was more explicit in describing how she was encouraged as a teacher through her participation in the project, “Everything that you guys gave us was tremendous. And it was like saying to us, or it felt to me that you guys were saying we believe in you and we want this to be successful.” Jane also felt encouraged as a teacher and talked about the idea that not only did she feel that she could do 3D Learning, but that any teacher could do 3D Learning and Teaching in their classroom, “I think what CORPS has taught teachers, that any teacher can do this. That it is easy to implement. They helped build my confidence. And then I felt like I was doing what I was supposed to be doing.” These participants explicitly described being encouraged as teachers and feeling increased confidence in their ability to implement 3D Learning and Teaching in their own classrooms.

External Structures: 3D Model and 3D Instructional/Assessment Task Format and Instructional/Assessment Tasks Database. All of the selected participants communicated how having the 3D model utilized in the project and how the 3D instructional task and 3D assessment task format helped them in developing their own understanding of 3D Learning and Teaching and in the process of planning and implementing 3D Learning and Teaching in their own classrooms. Irene pointed out that the 3D instructional task format became internalized for her in thinking about 3D Learning for her students,

> I think the format of the lesson plan helps us to plan a well thought out flow to the lesson. I now find myself thinking more about the steps and the sequence of the lesson. I think that keeps you grounded in what you're trying to teach them. But with this mode or style of teaching, incorporating all the things, you know, the questions, the analyzing, the ongoing assessments, the crosscutting concepts, I think that really brings out or brings up any, anything that you're doing from you know, because you're engaging them from the beginning I think they automatically step up and take it, you know. So, I mean, I kind of think it regulates itself if that makes sense.

Kara talked about how having the 3D model structure helped her be more purposeful in planning 3D Learning experiences for her students,

> Well in truth I see it's made it a little clearer on how I'm teaching things. It makes me sit down literally think a little more carefully about how I'm teaching, why I'm teaching, and what I'm teaching. By just making sure I

as a teacher, looked at all those steps to make sure which one I was going to use in that lesson. It makes me think more about where I want the kids to go with each skill that we do, and what I want them to get out of the skill, and how I want them to convey what they've learned back to me. And it makes me think, you know, what kind of ideas am I going to get from the kids if I do this?

Diana also spoke about how utilizing the 3D model and instructional task has allowed her to be able to internalize 3D Learning and Teaching,

> Just your step by step instructions of, OK this is what you want to look at don't focus on the big page just focus on this one as SEP or focus on this one DCI. So that that helped me tremendously. And so now when I look at my, when I look at that page in the book I'm like OK I need I know I need to do this this and this. And I can do it without necessarily writing it down. I can just do it out of my head, if that makes sense. It's made me more comfortable in saying, OK they're not getting it, or they are getting it. So, I can move to this. If they're not getting it, I can pull back and say OK this is what I need to refocus on. But it's very cyclical. Every time, every unit. What are they getting? What are they not getting? What can I do better? And what other resources can I use? Or how do I need to word it differently? Because it's not saying the same thing over and over and over again it's turning the question around to where they can understand it differently. Well I think I will do better developing more in-depth lessons or topics, standards, units.

Jane talked about how her whole view of developing learning experiences for her students has changed,

> Not only did they change my model on how I am and basically gave me a whole model so now I have a new model how to plan every time. They changed my whole lesson plan outlook. And so, they gave me exactly how to do a new lesson plan. They gave me how to do assessments and so they re-taught me how to teach, and plan for teaching, and then they gave me the stuff to do it and doing so they helped build my confidence. And then I felt like I was doing what I was supposed to be doing.

Jane went on to expand on exactly how her planning for student learning has changed, “Sequencing activities is part of the art of teaching – you have to experiment to see what works best. In general, it is better to do vocabulary first and vocabulary last.”

Miranda talked about how using the 3D model for student learning has restructured how she approaches the way she plans for and enacts 3D Learning in her classroom,

> Now when I'm writing lessons I try to start off with a phenomenon that catches them and I'm not going straight by the book and I'm not doing just worksheets or just multiple choice. Sometimes my students are confused but they're like why are we doing this? Because it's asking why. But I'm trying to do different things instead of just plain read the book answer the questions.

Miranda also spoke about having access to other 3D Instructional Tasks (ITs) and how that helped scaffold her in building her own 3D ITs, “The lessons we created we got to work to do ourselves. Kind of gave a scaffold for us to build.”

Jill spoke about her frustration with the 3D model in the beginning, but how now after going through the project it has become easier for her,

> There was a lot of frustration in there for me. I just couldn't get the format down. But being able to find it I think it's a little bit easier now and I think even with, as the year progressed and incorporating into the classroom it got a little bit easier.

In response to being asked what helped her with implementing 3D Learning, Jill spoke about having access to other 3D ITs, “Being able to just have the information or the database to go through and find lessons, even the assessments we developed over the summer.”

Each of these participants discussed in one way or another how having the 3D model and instructional task format were helpful for them in shifting the way that they think about student learning and how they implement learning experiences in their classrooms.

External Structures: Teaching Resources and Strategies. Three of the selected participants specifically mentions resources and teaching strategies that they received through participation in the project and how having these resources and strategies and having seen them modeled provided them with additional tools for implementing 3D Learning and Teaching in their classrooms.

Diana began by describing how having more teaching strategies has helped her grow as a teacher,

> I think my teaching has grown just by giving more giving me more resources to be able to give to the kids. And by resources, I mean verbal connections that I can say or verbal cues I can say for them. . . . Making sure that I've stated, you know, what do you notice? What do you wonder? I've stated, you know, all of those little catchphrases [strategies] that you guys taught us.

Diana went on to talk about how the physical resources that she received have influenced her teaching,

> I like the Green Book, the framework's book, it gave us specifically what we needed to be talking about and some misconceptions that the kids have. And it showed me, OK, let's focus specifically on this DCI. So, we knew what standard it was that we're supposed to teach. Just all of that information that you guys gave. The resources, the Paige Keely books that we got. Phillip Bell, that you guys brought in from STEM teaching tools. All of those resources that you guys did and all the activities that you did. I mean it just totally got me hooked.

Jane also described how important the resources were for her as she developed her 3D Learning and Teaching,

> CORPS also gave me a bunch of resources. Now I have resources to go to find things and I know what I need. They showed me how to do it and then they made it easy for me to do it. One thing it did is it made, it gave

me more stuff to do, more options and they even gave us a cool book [printed color copy of 3D science standards]. And so, I have more teaching tools because of CORPS. And then I've been given example after example how to do it.

Many of the participants in the project have utilized the printed color copies of the 3D science standards, making notations and using sticky notes to list phenomena and instructional task ideas relevant to specific PEs. Jane also talked about one of the outside resources brought in to help the teachers understand 3D assessment,

> The other thing that was really great was when the Phillip Bell came in and showed us how to look at assessments and how to make assessments of how to analyze assessments. And that's totally rocked my world and change how I was thinking.

Miranda also identified specific teaching strategies that she has utilized in her classroom,

> We did this one thing, we did Commit and toss. And so, I use that in class because I had done it and I really enjoyed it. So that really helped." and, "We really did the "I notice I wonder" and then we had them compare.

Jill has also utilized the I notice, I wonder strategy when having her students engage with phenomena,

> sometimes I'll have it up and they'll just begin discussing with their partners or the people near them. So, it's a conversation starter. It's a discussion starter. Some of them you could already hear them stating well I wonder if or I wonder that?

These participants have described specific physical resources and teaching strategies that have been helpful for them as they are implementing 3D Learning and Teaching.

External Structures: Peer Collaboration. One idea that most of the participants identified was that the ability to collaborate with other science teachers who are also in the process of transitioning to 3D Learning and Teaching. Since the project worked with teachers from rural school districts some of the participants have no science teaching colleagues in their home school district with whom to collaborate. Kara described how having the support of other teachers to talk to and discuss ideas made transitioning to 3D Learning and Teaching,

> It made it easier for me to have somebody to talk to that knew what I was talking about and knew some of the problems that they and they were trying to help us not have the same problems. That support was there, and that support was great.

Kara also reflected on the lesson study process they went through during year one of the project and the role of peer collaboration in that process,

> We field tested lots of lessons and lots of activities. And with that we got to communicate with other teachers from the areas, different areas that

> we normally wouldn't see. And we got to talk about how the lessons worked in our classes. And, you know, let's try this next time. Let's see if this will work better. And using that information, getting to talk to somebody else, it made me realize you know I'm not as bad as I thought. And with that I realize, you know, I can feel good about doing this, making an impact on how these kids are learning. And with information I'm sharing with the other teachers and they're sharing with me, it lets me see that impact is not just in my classroom that it's everywhere. It's a lot of places.

Diana also talked about how important it was to have other teachers to talk to, "I struggled a bit with how to present the phenomenon and it is helpful to get perspectives and suggestions from other people." Miranda discussed how having other teachers to talk to made an impact on her in understanding and implementing 3D Learning and Teaching,

> Being able to talk with other teachers at our workshop has really helped me. I'm the only science teacher that's at the CORPS project in my district. And so, I don't really have someone else to talk to at school. So, when I come here and able to talk to other teachers and find out what's worked for them what did they try that's different. And then like getting different ideas for labs or different resources and stuff has been the most helpful.

Miranda also discussed the role of collaboration in the modified lesson study process,

> I think when we created our lesson and then we got to go watch the other person teach our lesson. So, we got to see you know when we create a lesson and we teach it, or when I taught it I thought yeah everything went great just like I wanted to. But then when I saw someone else teach my lesson I'm like Oh why should have changed that. I could see my mistakes, where the places I need to correct.

Jill spoke about how being able to talk with her peers provided her with different perspectives and a larger personal database of phenomena,

> I think having the time to discuss with other teachers, as far as with the workshop during the summer, to identify different phenomenon. And having that ability to just bounce ideas off of each other. That helped. Just giving you more of a personal database. I used this and what do you use? I haven't found anything, but I do use this whenever I get to that topic. And that's when you can't think of everything on your own.

Jill also talked about how having another teacher from her school in the project was helpful as they could collaborate during the school year,

> Having another teacher as a voice to bounce off. Because, you know or being in the same hall we could always talk to each other as far as this worked. This didn't work. What did you do then if it didn't work? We can modify that day. That that helped tremendously.

The selected participants identified the importance of peer collaboration in their growth in understanding and implementation of 3D Learning and Teaching.

External Structures: Project Staff. A few of the participants indicated that having the support of the project staff helped them as they transitioned to 3D Learning and Teaching. Diana discussed the idea that knowing she was supported helped her in developing her 3D Learning and Teaching,

> I think knowing that you guys, here at the project, we could e-mail you. We could contact you. We could call you any way and if we had a question you guys were Johnny on the spot with I don't know the answer, but I'll get back to you as soon as I do or here I'll send you this resource or here's a web site I found. Just that knowing you had our backs. Knowing we could count on you if we, you know, like I struggle on the SEPs. Or I struggled that first time that we met on a Saturday and I didn't know how to how to make those instructional tasks. And then after just being with you guys and talking and knowing that you guys were here for us to back us up was nice for me.

Miranda described how the feedback from project staff during the first year of the project was helpful for her as she transitioned to 3D Learning and Teaching, “I think you guys' feedback was wonderful. Getting the feedback of what we could do to make it better. I think really had the most impact.” Jill described the importance of having the support of the project staff as she began implementing 3D Learning and Teaching utilizing the 3D instructional task format,

> I think it's hard to develop a 3-D lesson, in this format because that was the hardest part for me is putting it into this format on paper. I could do it.

> I could teach it. I could script it. But, I could not put it in this format. I could with help.

These participants talked about the role of project staff in helping them grow in 3D Learning and Teaching.

RQ5: What Perceived Outcomes Resulted from Participation in a 3D Learning-Focused Professional Development Program?

In order to answer RQ5, "What perceived outcomes resulted from participation in a 3D Learning-focused professional development program?", participant responses to the semi-structured interview were analyzed for relevant themes. One theme that emerged related to teachers' motivations to continue to develop their understanding and implementation of 3D Learning and Teaching. Motivation is the drive to be "moved to do something" (Ryan & Deci, 2000). Theme 3: Driving Motivations, centered on the reasons participants communicated that motivated the participants to continue to develop their understanding of 3D Learning and to continue to plan for and implement 3D Learning experiences for their students both as they participated in the project and after the project was completed.

Theme 3: Driving motivations. Theme 3 was composed of five components in which teachers described different aspects that motivated them to grow in their understanding of 3D Learning and Teaching and supplied the drive for them to continue to implement 3D Learning and Teaching in their classrooms (see Table 21 below). In the first component, participants discussed how through 3D Learning and Teaching they have found a restored joy in teaching, that teaching was fun again, and that this type of teaching provided hope for their teaching and the impact it would have on their students. In the second component, participants talked about instances in which they were able to see their students succeed and how seeing this success they were motivated to further implement 3D Learning and Teaching so that they might see continued success in their students learning. In the third component, participants described how implementing 3D Learning and Teaching in their classrooms has allowed them to teach the way that they have always

Table 21

Theme Three from Qualitative Analysis

Theme 3: Driving Motivation for Growth	
Codes	**Description**
Restored Joy/Hope/Fun to Teaching	Participants discussed the idea that teaching was "fun" again and that they found joy and/or hope in teaching when implementing 3D Learning.
Seeing Students Succeed	Participants described instances in which they planned for and implanted 3D Learning and how the success and engagement they saw with their students motivated them to plan for and implement additional 3D Learning experiences for their students.
Helps Me be the Teacher I Want to be	Participants discussed the idea that in planning for and implementing 3D Learning they are able to be the teacher that they want/have tried to be.
3D Learning Makes Teaching Easier	Participants discussed the idea that implementing 3D Learning made classroom management and other aspects of teaching easier.
Spread the Word	Participants communicated their hope/desire for other teachers in the state this project took place in to also experience similar growth in understanding and implementation of 3D Learning.

wanted to teach, in a sense to "be the teacher they wanted to be" (Irene). In the fourth component, the participants described that through utilizing 3D Learning and Teaching, teaching has been easier, especially in relation to classroom management. The fifth component, had, for the lack of a better term, an evangelistic property in which the participants conveyed how they desired for other teachers in their schools and in the state in which this study took place could take part in a similar growth experience centered on 3D Learning and Teaching. This theme is discussed in more detail and the results are presented in the following section.

Results.

Restored joy/ hope/ fun to teaching. Many of the selected participants made comments about how teaching had become fun again and how much they enjoy teaching using 3D Learning. Irene talked about how her participation in the project made teaching fun for her, "I think actually it [participation in the project] also made it [teaching] more fun. It made it more interesting. I felt like I learned from my own lessons." When Irene discussed her students as they engaged in 3D Learning she conveyed how she enjoyed teaching this way,

> I loved the students' reactions and I thought it was fun to teach this way. The students can feel the enthusiasm of the teacher and were totally engaged. The process of using a phenomenon is so engaging for the students and I love teaching this way.

Kara also spoke about how her students enjoyed learning this way and how that made her enjoy 3D Learning as well,

> Those standards and the way they're written and the way I use them, makes science more enjoyable for me to teach. It's fun and the kids enjoy it. So, it made me look at things differently to bring joy back into the teaching classroom. Instead of we got to teach it because it's on the test. Now I can do it because I get to do it, because it can enhance the skills that kids have to know for the test. Teaching was getting very boring.

Diana related how her success with 3D Learning has inspired her to continue to develop her 3D Learning and Teaching, "I'm loving it. And I want to do more next year with the assessments and all of that I think my instructional tasks are getting better."

Jane talked about how in implementing her 3D instructional task it was a new experience for her,

> I thought they could walk away knowing it and physically being there and being able to visualize it and draw a model at the end because they knew it so well. It was entertaining and chaotic. And they remembered it. The questions were kind of like how to get there? What caused this? What? It was like growing through the pavement. So how does it grow through the pavement? And so, so they generated a bunch of questions to. I was excited about that.

Miranda also referenced enjoying implementing her 3D instruction in relation to her students' engagement in the learning experience,

> I saw that they were more engaged and then it was easy to reference back. You remember when you made your message, remember when you saw the mutations, remember this and they could recall it. It was amazing to see students say well I have this answer. Why did you choose that answer? And actually, had dialogue because they're having to give reasoning, and it was it was really good to see that.

These participants communicated how they have experienced enjoyment through the process of implementing 3D Learning and Teaching in their classrooms. For some of these participants they described how teaching had become fun again for them.

Seeing students succeed. Another idea that the participants discussed both directly and indirectly was that they were able to see their students succeed and in seeing this success the teachers were motivated to continue to develop their understanding and implementation of 3D Learning and Teaching. For many of the participants it was seeing success in their classroom that caused them to fully invest in participation in the project. Irene spoke about the importance of getting to implement the 3D instructional task in her classroom and the impact that seeing success from that implementation had on her motivation to teach this way, “I'm very passionate about this and I learned so much. The lesson that I did, I mean really drove this home.” When asked to elaborate, Irene said,

> What was so surprising is that I thought some would be not interested, not engaged. I thought you know how would I handle that? What would I

> do if there were some that just weren't interested? But there was not a single student that was not interested. Which, was incredible. And so, as I walked around, and I saw other groups and they were making their notes, drawing their pictures.

She went on to describe her students' learning from the experience, "To come up with that concept based on what they saw and what they experienced through the experiment and it was better than I could have even imagined."

Kara also reflected on how having the opportunity to implement her 3D instructional task allowed her to see success in her students that further motivated her to develop her 3D Learning and Teaching,

> Doing it. Bringing it here and having to do it with my kids, and then getting to do with my kids. Because that let me see what we were learning there, was valuable in my classroom. And I could see the growth in my kid's knowledge and in their abilities.

Kara described that one aspect of this growth was how engaged her students were,

> I was just surprised and shocked at how well my bouncy group of kids settled in to learn about this stuff and learn about the bears and the science and the things that went with it and then they were excited to do the research. I have kids that hated to write, and they want to write more. They wanted to do more. We hit so much more than I thought, and I took it so much deeper than I thought it could take it. I thought, well I'm going

to do the one lesson get it over with and then I don't have to worry about it. Well, it turned into several lessons.

Seeing this success lead to Kara continue to implement 3D Learning and Teaching in her classroom,

> I did a lot more science with my kids and created an excitement with them about the science they were getting and with the different activities that we had done previously. They always wanted to know what we're going to do next.

Diana had a very similar account regarding her students becoming more engaged. Diana described how she has seen her students change their thinking about learning, “And you know they have a different growth mindset and it's changing for them. It's not, it's not an overnight thing that's for sure. But I can see the growth in the kids from last year to this year.” Diana also attributed her intentions to continue to implement 3D Learning and Teaching to her experience with field testing 3D instructional tasks with her students, “After I implemented a few that we had done that summer. And after doing those a few times and then seeing how the kids reacted differently to my different teaching. That just made the fire even bigger within me.” She went on to reflect on the impact that her transitioning to 3D Learning and Teaching has had on her students,

> They're just more engaged and they're all paying attention and they're all doing what they're supposed to be doing. Because I get, I get so excited

> because I see how they have changed. And then it makes me want to do even better.

Jane discussed how teaching using 3D Learning has altered her teaching style, “It was more student led than I have ever let it be. And it was one of the best days ever because they got so excited about why the phenomenon occurred and so we did.” Jane also described how she has seen an increase in student collaboration since implementing 3D Learning and Teaching, “Teaching this way has resulted in more science conversation from students because you are engaging them more and the conversation you get is amazing.” Likewise, Miranda talked about the success she saw in her students becoming more collaborative with other students and able to communicate their thinking about the targeted DCI concepts , “It was amazing to see students that are special-ed students say well I have this answer. Why did you choose that answer? And actually, had dialogue because they're having to give reasoning.” Miranda described how her students’ perspective of science has changed as she has implemented 3D Learning and Teaching,

> I've seen students that would come in at the beginning of the year and they told me, ‘I hate science I don't like science.’ And then just last week that student that told me that was so engaged he wanted to stay after class because he wanted to know something.

Miranda discussed how she has tried 3D Learning along with teaching strategies in one or two classes and seeing success in these field tests has driven her to expand this style of teaching to all her classes,

> That's helped a lot. Because, like one day I just decided let's try commit and toss and so we did commit and toss to see how that worked and then I'm like OK that works. So, then I could work that in two other ones. So just trying it out in small spots or with smaller classes. And when it works with them I can do it with the larger classes.

Jill, like the other participants, described trying out 3D Learning and seeing success that lead to implementing more 3D Learning experiences into her classrooms,

> I think it’s just the experience and presenting it to students. And if was successful with them, then that kind of calms my hesitations. So, you want to, just like the students want to please the teachers, I want to keep them happy. And if it worked and it helped them learn, I want to keep doing that. So, their feedback really helped with that process.

Each one of the participant recounted instances when they field tested 3D Learning as well as teaching strategies to facilitate 3D Learning. As the tested this type of teaching out for themselves, they were able to see their students achieve success in different areas (e.g. engagement, collaboration, communication, conceptual understanding). Being able to test out 3D Learning and seeing their students find success motivated them to move forward in transitioning to 3D Learning and Teaching.”

Helps me be the teacher I want to be. All of the selected participants identified that through participation in the project and transitioning to 3D Learning and Teaching they are able to teach in ways that are congruent with how they have wanted to teach. Irene reflected on how she feels she has become a much better teacher as a result of participation in the project, “I feel like that it's kind of brought out and taught me to be a better teacher than I was when I graduated college.” Irene went on to elaborate on what she meant by that statement,

> You know that it truly is the teacher that I want to be, this teacher that comes from, you know, the SEPs and the crosscutting concepts. Because then also I think those things lead into that assessment portion more naturally.

For Kara she had described how she wanted to teach science more in her classroom but did not feel she could with the demands of other subjects, however participation in the project has changed her viewpoint about this, “It just made me more adamant to make sure science is included in my classroom. And not left out.”

Diana also talked about becoming a “better” teacher as a result of participating in this project and through transitioning to 3D Learning and Teaching,

> It's just ignited a fire. It makes me a better teacher. What I take from it? I can do better teaching the kids. And I know that they can do better learning. They've never been pushed before. And this pushes them to think on their own. It has made me more engaged with the kids and I've learned more about how they learn. Now I'm more focused on what I know I need to teach and what I want them to come out of it with.

Jane has sought out opportunities to improve her teaching practice and strives to be an inquiry-based teacher, however she describes how she has been able to make this shift as she has participated in the project to transition to 3D Learning and Teaching,

> The last three years I've done lots of things to try to become a better teacher. And I have I gone to different workshops, ones that have implementing music in the classroom and brain breaks and teach like a pirate. And then I go to CORPS and it has been a phenomenal difference and I have enjoyed teaching and gotten so much more confidence because I had so much better results.

Jane described her teaching practice before and the impact of 3D Learning on her pedagogy,

> I've always tried to steer away from worksheets as much as I can and try to do a little bit of everything. And try to make things as hands-on as possible and not do book work all the time. And this year I've actually accomplished that. Where my book is a resource and none of my students feel like they ever do anything in the book.

Miranda reflected on her experiences with transitioning to 3D Learning and Teaching through the project and how her thinking about teaching and learning have shifted,

> I guess learning that it's not so important to have the exact answer as it is to have these science thinking, the way of thought. I got so stuck at the beginning you have to have this answer that, you know, kind of puts off

> some of those students, they have the right answer, but just couldn't express it in the way I wanted them to. And then just learning different ways of reaching those other students has helped, a lot. So, I feel like I'm a stronger teacher because I try to attack from different angles.

Jill also talked about how she had to change as a teacher, but that this change is necessary for her to help her students succeed,

> I knew I needed that as far as learning how to do that. But, it’s that hesitancy as far as learning something new. When you're far into your career do you really want to change? Do you want to be successful? Yes, you do. And you have to. Kids change all the time.

These participants discussed how they have been able to change aspects of their thinking about teaching and learning and their teaching practice through transitioning to 3D Learning and Teaching as they participated in the project.

3D Learning makes teaching easier. These selected participants described that as they have shifted their teaching practices and implemented 3D Learning and Teaching that aspects of teaching have become easier as a result. Irene communicated that she felt more equipped as a result of participation in the project, “ I feel like it gave me tools that I didn't have coming out of college.” Kara talked about how having the experience of the project and having and understanding of the 3D science standards and 3D Learning has made it easier for her plan and implement student-centered learning experiences for her students to the point that she is integrating science with her other subjects and even seeking funding for supplies that will help facilitate student learning,

> I've kind of went through the standards and looked at it and said OK I can do this with reading and I can make this story not so boring. I can do this activity because, hey it's in the standards and the kids like this. To where in the past, it was like I don't want to do it, it’s too messy. Now I'm like yeah, we can do it. It made me write a grant to get tables so that I could have a bigger area for the kids to do the activities on.

Diana talked about how she has even been able to think scientifically and look for phenomena in her experiences outside the classroom that she can bring back to her students,

> I was on vacation in Arizona and we were at the Grand Canyon and there was green moss growing on one side of a rock and white stuff growing on another side of the rock. So why is that? Why is it green on one side and why is it why on the other side? And so, it makes me, the phenomenon makes them more engaged and makes them wonder what is she going to come up with next? or Why is that? I don't know. I mean most of them at the beginning are like, "I don't know, science I guess". And now they want to know How? Why is it, why is it like that? Well, that's cool!

Jane reflected on how she has changed as a teacher and how these changes have impacted her teaching practices in the classroom, “Everything about CORPS has been making my life easier and making me a better science teacher because I'm teaching more science and less notes." Jane explicitly talked about how classroom management has become much easier as she has transitioned to implementing 3D Learning and Teaching,

> Before I came to this three-year journey, is, I never would just give my students a bunch of supplies and tell them to design their investigation and I'm doing that a lot. Where I'm having them design their own investigation. They have to be engaged, they have to be knowing what we're doing in order to do that. So, yes that's been crazy as far as me saying here's some magnets go investigate as a from a classroom management perspective. But it works and in some ways it's an easier classroom management day.

Miranda talked about using her time during the summer to plan more 3D Learning experiences for her students,

> I've used it as much as possible for the moment. So, my plan this summer is to go back over some of my content and add more 3D to it. So, I have maybe seven or eight lessons that I want to really work on and strengthen.

Jill discussed how she has felt more freedom in how she plans learning experiences for her students in that she can be more flexible in the pacing and order of content her students are investigating,

> With traditional teaching you always think that you have to do this unit at this time, this unit at this time. Where with this project you can actually

identify and incorporate multiple units within one idea. That's how life is.

It makes it a little bit easier to actually be able to teach the students.

These participants have identified different ways in which teaching has become easier for them (such as classroom management, planning, confidence, and autonomy) as a result of their participation in the project as they have transitioned to incorporating 3D Learning and Teaching into their instructional practices.

Spread the word. Many of the participants expressed that they wish that other teachers could take part in this type of professional learning experience. Some of the participants also expressed that they hope that other teacher could teach this way and transition to 3D Learning and Teaching. Irene more than once mentioned that she felt that student-centered learning congruent with 3D Learning and Teaching is in her view the only way to teach in every subject,

> I quite honestly think this is the only way to teach from science, to math, to social studies, to English, to reading. I think it is absolutely the best and only way to teach. I'm so thankful that I got to be a part of that.

Kara talked about how she wanted other teachers to get the same experience that she had so that other elementary teachers can become more confident in teaching science and not be afraid to teach science,

> We need to take this to more teachers and we need to get it to more teachers. To give them the same confidence and excitement and not to say I hate science and to make them take it to them and let them realize

that it is something they can do even if they have no science knowledge. It is possible to enjoy science.

Similarly, Diana spoke about wanting teachers from across the state to experience 3D Learning, “This has been an amazing experience and I would I wish everybody in the state could do it and not just this CORPS sample of people.” Like Diana, Miranda would like for other science teacher to teach using 3D Learning in their classrooms, “Well I can see a difference in the students learning from learning three dimensionally not just rote memorization. And so, I think other science teachers should teach the way I teach.” Jane has become so invested in 3D Learning that her and another teacher in her school that participated in the project are working with one of their colleagues to bring her on board with transitioning to 3D Learning and Teaching,

> My friends and I are working hard, and I have a co-worker that got to do CORPS the last two years too. And her and I are trying to get our third team member to not rely on the book as much. And to try to teach her how to ask the harder questions and to put in. So, we've given her the [projects] links and we've tried to show her and give examples as much as we could to try to do this for her.

These teachers have seen the value of 3D Learning as they have transitioned to this style of teaching and as a result they have expressed how they believe that it would be useful for other teachers as well.

Conclusion

This study utilized a two-phase sequential explanatory mixed methods approach to conduct data collection and analysis. Phase One consisted of data collection through two Likert-type surveys administered pre-project, mid-project, and post-project. These surveys were designed to measure teachers' understanding of and confidence with 3D Learning and Teaching as well as their self-reported level of use in implementing 3D Learning and Teaching. Statistical analysis was performed on the results of both of these surveys to answer RQ1 and RQ2. This analysis was utilized to construct two lists of teachers at each grade band; List One showed participants with the largest growth in their confidence and understanding of 3D Learning and Teaching, and List Two showed participants with the largest growth in implementation of 3D Learning and Teaching. Three participants were selected from each list to participate in Phase Two. In Phase Two, teachers participated in interviews designed to cause the teachers to reflect on their thinking about teaching as they planned 3D Learning student experiences, the implementation of 3D Learning and Teaching in their classrooms, and their experiences that were formative for them as they participated in the project.

The results in response to RQ1, "What are the characteristics of teachers identified with significant growth in understanding of 3-Dimensional Learning?" were presented in this chapter. Only 36 of the 67 participants completed the post-project survey. This limited the number of participants with available data to answer RQ1. Out of the top 50% of the 36 participants, the majority (77.7%)

were elementary teachers. When looking at the top ten participants, 54.5% of these participants had previously participated in professional development experiences with the organization who facilitated the project that was the focus of this study. Through examination of the distribution of scores it was found that they were negatively skewed. The participants' years of teaching experience were analyzed for a correlation in relation to their understanding and confidence in 3D Learning and Teaching and a weak positive correlation was found.

The results related to RQ2, “What are the characteristics of teachers identified with significant growth in the implementation of 3-Dimensional Learning?” indicated that of the top 50% of the total 67 participants, the majority were elementary teachers (70.2%). When looking at the distribution of scores it was found that they had a negative skew. In comparing the participants' years of experience in teaching to their growth in implementing 3D Learning and Teaching and a weak positive correlation was determined.

The results related to RQ3, “How does teachers’ 3D-PCK translate into their classroom instructional practices?” were presented in emergent Theme 1: Evidence of Growth. Within Theme 1, there were five codes and one sub-theme with four codes that emerged from the qualitative data analysis. Participants discussed how they progressed from feeling frustrated at the beginning of the project to being confident in their understanding of 3D Learning and Teaching. Participants also explicitly described a shift from a teacher-centric role to a role as a student-centered facilitator. From this student-centered viewpoint, participants talked about carrying out learning experiences in which students were able to experience and develop concepts for themselves. Teachers were able to reflect on how their teaching had shifted as a result from participation in the project. The participants also gave various examples of 3D Learning and teaching in practice as they implemented their new style of teaching in the classroom. These examples were presented as PaP-eRs presenting these examples through interview narrative accounts. All of these data were presented in relation to how teachers translated the PCK from a 3D-focused context into classroom learning experiences for their students.

The results related to RQ4, “What experiences within the first year of a three-year 3D Learning-focused professional development context can lead to growth in teachers’ understanding and implementation of 3D Learning and Teaching?” were presented in emergent Theme 2: Growth Support Structures. Growth Support Structures was composed of two sub-themes, Internal Structures and External Structures. The Internal Structures sub-theme had four components identified in the qualitative analysis. Participants discussed these Internal structures as opportunities, such as the opportunity to engage in self-reflection about teaching practices and beliefs, the opportunity to gain experience with understanding 3D science standards and the dimensions that comprise the standards, the opportunity for teachers to participate in learning experiences from the role of the learner allowing the participants to have the perspective of their students, and the opportunity for participants to feel encouraged about their teaching practice and to believe in their ability as a teacher to implement 3D Learning and Teaching. The External Structures identified by study participants included having the 3D instructional model and format as a structure to support teachers in planning 3D Learning experiences, access to the project 3D Instructional and Assessment Task database providing teachers with model tasks to field test in their classrooms, physical resources and teaching strategies provided participants with additional tools to carry out 3D Learning and Teaching, the ability to collaborate with peers provided a support system for teachers to work together in transitioning to this style of learning, and having the support of the project staff to provide assistance throughout the process.

The results related to RQ5, “What perceived outcomes resulted from participation in a 3D Learning-focused professional development program?” were presented in emergent Theme 3: Driving Motivations. Theme 3 was comprised of five ideas that participants identified that served to motivate them to grown in their understanding and implementation of 3D Learning and Teaching. The study participants described feeling a restored enjoyment to their teaching and that teaching had become fun again. One of the main ideas that all the participants discussed was that when they saw success in their students that motivated them to push forward in transitioning to 3D Learning and Teaching. The participants talked about how utilizing 3D Learning with their students helped them teach in ways that were more congruent with who they wanted to be as a teacher. Many of the participants described how utilizing 3D Learning actually made teaching easier in their classroom. Lastly, teachers shared a desire for other teachers to have the opportunity to experience similar professional learning centered on 3D Learning and Teaching.

The next chapter discusses possible interpretations of the data presented in this chapter and any resulting implications. The 3D-PCK framework is utilized as a lens for interpreting these results allowing me to make connections between teachers' experiences and their PCK as it developed in the context of a sustained 3D Learning and Teaching focused professional learning experience. Limitations and strengths of the study are discussed as well as possible avenues for future research into teachers' 3D-PCK. Final conclusions regarding the importance and role of 3D-PCK as both a research framework and a tool for teachers, administrators, pre-service teacher programs, and professional development providers are discussed.

Chapter 5: Discussion and Implications

Introduction

The quantitative and qualitative findings of this study are discussed and related to the proposed 3D-PCK framework utilized for this study. The findings are discussed in relation to the research questions that guided this study.

1. What are the characteristics of teachers identified with significant growth in self-reported understanding of 3-Dimensional Learning?
2. What are the characteristics of teachers identified with significant growth in the self-reported implementation of 3-Dimensional Learning?
3. How does teachers' 3D-PCK translate into their classroom instructional practices?
4. What experiences within the first year of a three-year 3D Learning-focused professional development context can lead to growth in teachers' understanding and implementation of 3D Learning and Teaching?
5. What perceived outcomes resulted from participation in a 3D Learning-focused professional development program?

Firstly, the 3D-PCK framework is discussed as a possible lens through which the findings from this study can be interpreted. Secondly, the findings related to each RQ will be discussed and connections to 3D-PCK will be identified. Thirdly, the possible implications of these findings will be presented. Fourthly, the limitations and strengths of this study are discussed. Fifthly, directions for future research related to 3D-PCK are presented. Finally, the overall conclusions of this study are presented for consideration.

Definition and Use of 3D-PCK as a Framework

3D-PCK (see Figure 16) as previously discussed in Chapter Two was utilized as a framework to relate the qualitative findings from this research study. Three-Dimensional-PCK, or the application of PCK within a 3D Learning context, in this study utilized the components of PCK (Content Knowledge, Pedagogical Knowledge, and Contextual Knowledge), to investigate individuals who are transitioning to new modes of teaching that is focused on 3D Learning.

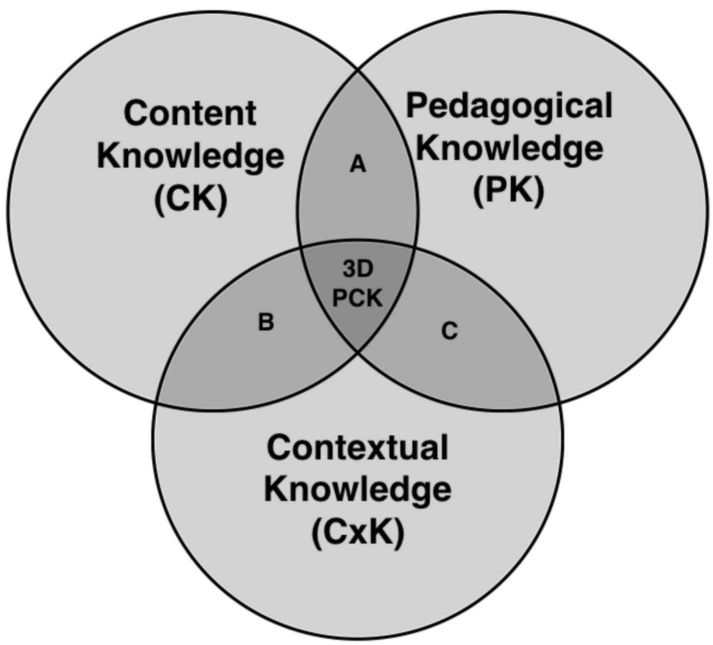


Figure 16. 3D-PCK Framework

Teacher Content Knowledge (CK) includes knowledge of each of the three dimensions within the *Framework* (NRC, 2012), including the Science and Engineering Practices, Crosscutting Concepts, Disciplinary Core Ideas, and how to integrate them into learning experiences for students. Teacher

Pedagogical Knowledge (PK) includes instructional strategies and planning for successful 3D Learning and Teaching in the classroom. Teacher Contextual Knowledge (CxK) includes knowledge about their students and the possible cultural funds of knowledge related to the scientific concepts and related phenomena focused on during instruction. Each of the emergent themes described in the next section of this chapter were examined for possible connections to each component of 3D-PCK (CK, PK, and CxK). The 3D-PCK Framework served as a lens to organize and understand teachers' PCK in relation to 3D Learning and Teaching. These connections will be discussed in relation to RQ3, RQ4, and RQ5 in the following sections.

Discussion of Findings

Quantitative Findings. In Chapter 4, the quantitative data from participants involved in Year 1 of the project were presented as a part of Phase One of this study. In the following sections, these data will be discussed in relation to RQ1 and RQ2. These data will also be discussed in relation to 3D-PCK.

RQ1: Characteristics of teachers with growth in understanding of 3-Dimensional Learning. Current reform efforts regarding science education are moving science educators to shift from more traditional modes of teaching, which focused on content alone or content and science processes, to teaching using three dimensions integrated together in instruction and assessment (National Research Council, 2012; NGSS Lead States, 2013). Teachers in many states are at various stages of transitioning to 3D science standards

(National Science Teachers Association, 2018). Teachers utilizing 3D Learning attempt to focus their students on engaging them in the practices of science and engineering (SEPs) and the thought processes scientists and engineers often employ (CCCs) to apply disciplinary core ideas (DCIs) to explain phenomena (National Research Council, 2012; NGSS Lead States, 2013). These teachers in the process of transitioning to 3D Learning and Teaching will require ongoing support and professional development in order to achieve 3D Learning and Teaching in their classrooms (NASEM, 2015; NRC, 2012).

The teachers participating in this project were working towards implementing 3D Learning and Teaching in their classrooms for their students. As a part of this project, their understanding of 3D Learning and Teaching was measured pre- and post-Year 1 of the project. The average growth in understanding of 3D Learning was 43 with a range of 64 (67-3) and a *SD* of 16.83. A larger *SD* indicates that participants scores were more spread out from the mean growth resulting in more variation among the growth of participants' understanding of 3D Learning. This means that in the first year of the project, the participants experienced different levels of growth in understanding 3D Learning and Teaching. This could indicate that the teachers were growing in their understanding of 3D Learning and Teaching at different levels and could require different levels of support when transitioning to 3D Learning and Teaching. Some teachers may be more able to make this transition more easily than others, while some teachers may require more intensive ongoing support to make connections to their classroom practices, to overcome viewing the necessary shifts through the lens of their traditional teaching viewpoints, make application directly to their classroom, and to focus on “high leverage practices” to focus participants on teacher-educator pedagogies that have “high pay-off in the classroom” (Garet, Porter, Desimone, Birman, & Yoon, 2001; Heller, Daehler, Wong, Shinohara, & Miritrix, 2012; Reiser, 2013).

Another interesting finding was that when looking at the participants showing growth in 3D Learning and Teaching above the mean, 79% were elementary teachers and 53% of those showing growth in 3D Learning and Teaching below the mean were elementary teachers. This indicates that among the participants (elementary school, middle school, and high school) elementary teachers grew more in their understanding of 3D Learning and Teaching than their colleagues’ teaching older grade levels. Through my interactions with the elementary teachers in this project, many indicated to project staff that the teaching of science at the elementary levels was not a priority in their classrooms and that if science was taught it was rarely taught. This reluctance to teach science at the elementary level may be because elementary teachers may not be teaching science as frequently as teachers who specifically teach science in middle school and high school because they do not feel confident in their science content knowledge or science related pedagogy. This is confirmed in examining the related research regarding the frequency science is taught at the elementary level (Appleton, 2008; Poon, Lee, Tan, & Lim, 2012; Slater, 2017; Trygstad, Smith, Banilower, & Nelson, 2013).

Both the participants' years of experience in teaching in general and teaching science specifically were analyzed to determine if any correlation was present. A weak positive correlation exists between these variables. One interpretation of this finding could be that it would be expected that more experienced teachers would be able to make the transition to new styles of teaching having a wealth of teaching experience to draw on and apply the new style of teaching. It could also be argued that teachers with more years of experience could be set in their ways and that it would be more difficult for these teachers to change to new modes of teaching. However, in this study only a weak positive correlation could be determined between teachers' years of experience and the amount of growth in understanding 3D Learning and Teaching. One reason for this finding could be that because 3D Learning is such a new construct in science education it requires such a large shift in thinking about teaching and student learning. In a sense, this newness equalizes the field for all the teachers attempting to make this transition so that the years of experience has little to no effect on the success of teachers' growth in understanding 3D Learning and Teaching. It has been documented that the shifts required for 3D Learning outlined in the *Framework* (NRC, 2012) will be significant and that teachers will need ongoing intensive support in this process (Moulding et al., 2015; Reiser, 2013).

An additional finding was that when looking at the top ten participants at each grade band (elementary, middle, high) 54.5% had previously participated in PD experiences facilitated by the organization facilitating the 3D Learning-focused PD project this study investigated. The center facilitating the PD for the CORPS project holds Authenticity as part of their core beliefs about teacher and student learning. They utilize an authenticity framework, which has student-centered learning as a major focus, to guide the design of teacher and student learning experiences (Newmann, Bryk, & Nagaoka, 2001; Newmann, King, & Carmichael, 2007; Newmann, Marks, & Gamoran, 1995; Newmann, Secada, & Wehlage, 1995; Newmann & Wehlage, 1993). This focus on authenticity and student-centered learning in their design of PD indicates that these participants had previous experience with professional development focused on student-centered learning. This previous experience with student-centered learning PD may have provided an advantage for these teachers in making the transition to 3D Learning and Teaching which focuses on directly engaging the students in the SEPs, CCCs, and DCIs to make sense of DCI-related phenomena (Achieve, 2016; National Research Council, 2012; NGSS Lead States, 2013).

Alternately, when looking at the participants' total prior PD experience directly focusing on 3D Learning and Teaching only 5.56% had previously engaged in PD centered on 3D Learning from any organization. Of the few that did have experience with 3D Learning focused PD their experiences varied as some had attended State Department of Education regional PD and others attended PD conducted at their individual school site. Focusing only on the top ten participants at each grade band (elementary, middle, high), 9% of these participants had previously experienced PD focused on 3D standards and learning. The fact that such a small percentage of the participants had any previous experience with PD focused on 3D Learning indicates that those top ten participants showing growth in 3D understanding had little to no previous background experience with 3D Learning and Teaching. This again served to place the participants on equal footing as they began the process of transitioning to 3D Learning and Teaching through the project.

Connections to 3D-PCK. Regarding RQ1, the quantitative data related to the participants'; growth in understanding of 3D Learning and Teaching was presented and discussed. Connections between data related to RQ1 and the proposed 3D-PCK framework are explored in this section. Three-Dimensional PCK as defined in this study consists of three intersecting components, teacher content knowledge (CK), teacher Pedagogical Knowledge (PK), and teacher Contextual Knowledge (CxK). RQ1 and the findings related to this question focus primarily on the CK component of 3D-PCK. This includes the traditional thinking about content knowledge as having a sound understanding of one's domain specific science knowledge (Gess-Newsome, 1999; Magnusson, Krajcik, & Borko, 1999). Teacher CK in a 3D Learning context is expanded to include teachers' understanding of 3D standards and the three dimensions that comprise the standards (SEPs, CCCs, and DCIs) as knowledge of the DCIs relevant to a specific grade level and domain requires science specific knowledge in addition to the role of phenomena in 3D Learning (National Research Council, 2012; NGSS Lead States, 2013).

As indicated in the data analysis and discussion the teachers in this project increased their understanding of the 3D science standards and 3D

Learning and Teaching. Through increasing their understanding in this area these teachers, especially the elementary teachers were able to increase their CK. Through the project, teachers were able to deeply explore the 3D standards to get a general overview and were given opportunity to explore each dimension in depth. These experiences provided them the opportunity to engage in the content at their grade level and to make the connections between the SEPs, CCCs and the DCIs. Through the job-embedded nature of the professional learning, teachers were able to make application of these three dimensions and their classroom practices. Making applications of 3D Learning the teachers necessitated and increased their understanding of the three dimensions and phenomena and how they work together in student learning of science.

In addition to increasing their CK, the participants were able to increase their PK. This is evident in the teachers increased understanding and confidence in using the SEPs and CCCs to engage their students to investigate and explain phenomena related to the DCIs at their respective grade levels. The data related to RQ1 do not indicate that participants learned specific teaching strategies to help with 3D Learning and Teaching. However, the nature of the SEPs requires teachers to shift their thinking about teaching from a teacher-centered viewpoint to a student-centered viewpoint. During instruction, the SEPs focus the teacher to guide the students in engaging in the practices in which scientists and engineers typically engage to make sense of science ideas (Moulding et al., 2015; National Research Council, 2012; NGSS Lead States,

2013; Schwarz, Passmore, & Reiser, 2017). Through increasing understanding of the SEPs, teachers were able to increase their knowledge about student-centered pedagogy and the importance of having students engage in the SEPs to make sense of the science ideas they encounter in their classroom.
This means that the project participants were able to increase both their CK and their PK and are developing a more robust PCK within a 3D context. In essence, these teachers are developing their 3D-PCK.

RQ2: Characteristics of teachers with growth in implementation of 3-Dimensional Learning. In addition to measuring teachers' growth in understanding of 3D Learning and Teaching, the participants' self-reported implementation was measured using the CBAM Levels of Use Survey (George et al., 2008). The maximum growth in 3D Learning implementation teachers experienced over the course of the project was 24 with a range of 24 (24-0). The mean growth was 13.68 and the *SD* was 5.46. The smaller *SD* indicates that the teachers' growth in 3D Learning and Teaching implementation was close to the mean. This indicates that there was not much variation in the range of growth for 3D Learning and Teaching implementation in the participants as they transitioned to 3D Learning and Teaching through the project. This could mean that although there were larger variations in the participants growth in understanding 3D Learning as previously mentioned, the teachers appeared to move toward 3D Learning and Teaching implementation more equally. A mean of 13.68 indicates that on average the teachers increased their implementation of 3D Learning at least 2-3 points over the fives components measured on the

CBAM Levels of Use Survey (SEPs, CCCs, DCIs, PEs, 3D Learning). That means for those teachers initially starting at a zero, non-use level, they now would report to be in a preparation or mechanical use stage. For teachers already starting at a higher level of implementation such as preparation or mechanical use they would have grown in implementation anywhere from refinement to renewal. Similar to encouraging understanding of 3D Learning and Teaching, teachers attempting to implement 3D Learning and Teaching will need ongoing, job-embedded support (Garet et al., 2001; Heller et al., 2012; Reiser, 2013). This finding indicates that the support structures present in the first year of the project to help teacher implement these reforms in their classrooms was more successful in equally supporting teachers in implementation of 3D Learning and Teaching than in developing understanding equally across all participants. These support structures will be discussed in a subsequent section.

Another finding related to RQ3 was that 70% of the teachers who grew in their self-reported implementation of 3D Learning were elementary teachers and 60% below the mean were also elementary teachers. The reason for this large increase in the elementary teachers' 3D Learning and Teaching implementation could be that as discussed in the previous section prior to participating in this project science was not frequently taught in the elementary classrooms (Appleton, 2008; Poon et al., 2012; Slater, 2017; Trygstad et al., 2013). It seems logical to infer that teachers that are not currently including science instruction in their classroom would grow the most in implementing 3D science Learning and Teaching compared to teachers at higher grade levels that regularly teach science. One interpretation of this finding could be that as a result of participating in the project elementary teachers have come to see the value of science learning for their students and have shifted their thinking about the importance of regularly including science learning in their classrooms. When teachers value something, such as science learning, they are more likely to be motivated to engage in that activity in their classroom (Ryan & Deci, 2000).

Similar to the findings related to RQ1, teachers' years of experience with teaching and with teaching science were analyzed for any correlations with their growth in 3D Learning and Teaching implementation. A weak positive correlation was determined between teachers' years of teaching experience and growth in implementation of 3D Learning and a weak negative correlation was found between teachers'' years of experience teaching science and growth in implementation of 3D Learning. The reasons for this finding are similar to the reasons that weak positive correlations were found between teachers' years of experience and growth in understanding of 3D Learning and Teaching. Three-Dimensional science Learning and Teaching as a reform are relatively new and for all teachers, regardless of how long they have been teaching, 3D Learning and Teaching is a new construct that requires significant shifts in both their thinking about instruction and their practices (Moulding et al., 2015; Reiser, 2013).

When looking at the top ten participants at each grade band (elementary, middle, high) it was found that 40% had prior experience participating in PD that was facilitated by the organization facilitating the 3D Learning focused PD project this study investigated. As discussed in relation to RQ1, this organization utilizes an authenticity framework to guide the design and implementation of teacher and student learning experiences (Newmann et al., 2001; Newmann et al., 2007; Newmann, Marks, et al., 1995; Newmann, Secada, et al., 1995; Newmann & Wehlage, 1993). Having previous professional learning experiences with student-centered learning could be advantageous as these participants transition to 3D Learning and Teaching aligned to the *NGSS* and the *Frameworks* (Achieve, 2016; National Research Council, 2012; NGSS Lead States, 2013). This means that teachers with more experience in student-centered learning may be more able to easily transition to 3D Learning and that by providing PD for teachers focusing on student-centered learning could serve to better equip teachers to transition to 3D Learning.

When looking at the previous PD experience of the top ten participants at each grade band showing growth in implementation of 3D Learning and Teaching that directly related on 3D Learning and Teaching, 23.3% had prior experience with PD centered on 3D Learning. As discussed with RQ1 this indicates that those top ten participants showing growth in 3D understanding had minimal background experience with 3D science standards and 3D Learning and Teaching. This means that the participants were entering the project with fairly equal experience with implementing 3D Learning and Teaching as they began the project. By starting with similar experience with 3D

Learning the participants were more able to grow together as they transitioned to 3D Learning. This could have implications for other PD facilitators as they take into account the starting levels of the participating teaches when planning and implementing teacher learning experiences.

Connections to 3D-PCK. In relation to RQ2, the quantitative data regarding participants' growth in the self-reported implementation of 3D Learning and Teaching was presented and discussed. The connections between the findings related to the participants growth in implementation of 3D Learning and Teaching and the proposed 3D-PCK framework are described in this section. Whereas RQ1 highlighted teachers' CK, RQ2 focuses more directly on teachers' PK. The inference can be made that if teachers are reporting increasing their implementation of 3D Learning and Teaching that they are more confident in their understanding of what 3D Learning and Teaching is (CK) than teachers not implementing 3D Learning and Teaching.

Additionally, teachers reporting increased implementation of 3D Learning and Teaching might indicate that teachers have gained the needed pedagogical skills and strategies to craft meaningful 3D Learning experiences for their students (Kind, 2009). This would mean that these teachers had an increased PK related to 3D Learning and Teaching. Based on these findings we can make the possible inference that the participants in this project were able to develop their PK and CK in relation to their overall 3D-PCK. The validity of these inferences can be strengthened by looking at the qualitative experiences and reflections of the teachers as they implemented 3D Learning and Teaching in their classrooms in an effort to triangulate the findings (Merriam, 2009).

Qualitative Findings

The qualitative data for the six participants who were selected to take part in Phase Two of this study were analyzed for emergent themes and these themes were presented in Chapter 4. In the following sections each theme will be discussed in relation to RQ3, RQ4, and RQ5 and when appropriate connections will be made to 3D-PCK. The data will be discussed in a slightly different order than presented in Chapter 4. First RQ4 and Theme 2: Growth Support Structures will be discussed and then RQ3 and Theme 1: Evidence of Growth will be discussed. Finally, RQ5 and Theme 3: Driving Motivations will be discussed. The reason for discussing the RQs and Themes in this order is that Theme 2: Growth Support Structures, the structures and experiences that teachers indicated as important for their growth in understanding and implementing 3D Learning and Teaching, provides the mechanisms responsible for Theme 1, the Evidence of Growth communicated by the teachers. In this way the teachers' experiences during Year One of the project will be discussed in relation to RQ4 and the implications of these experiences, the growth and implementation will be discussed in relation to RQ3. RQ 5 and Theme 3 will then be discussed in the context of results that emerged from participation in the project and the related classroom implementation of 3D Learning and Teaching. Connections to 3D-PCK will be integrated into the discussion when relevant and appropriate.

RQ4: Teachers' experiences within a three-year 3D Learning focused professional development context leading to growth in teachers' understanding and implementation of 3D Learning and Teaching. The emergent theme related to RQ4, Growth Support Structures, provided insight into the experiences, described as Internal and External structures, that teachers identified as important in their development of their 3D-PCK. These structures also provided scaffolding for the teachers to be successful in their implementation of 3D Learning and Teaching in their respective classrooms. Additionally, the emergent theme related to RQ3, Theme 1: Evidence of Growth, provided insight into the growth outcome experience of the selected participants as evidenced in their shifts in thinking about instruction and in how they carried out 3D instruction in their classrooms. The Growth Support Structures and the related Evidences of Growth will be discussed in this section. First the Internal Structures and related Evidences of Growth will be discussed and then the External Structures and related Evidences of Growth will be discussed.

Opportunities for self-reflection and self-realization. The Internal Structures presented themselves as opportunities that the teachers were able to engage in and with during Year 1 of the project. One key characteristic of effective PD are experiences that promote participant reflection (T. R. Guskey, 1999; Thomas R Guskey, 2002; Loucks-Horsley, Stiles, Mundry, & Hewson, 2009). The participants in Phase Two of the study identified multiple moments when self-reflection positively impacted their experience as they transitioned to 3D Learning and Teaching. These moments of self-reflection relate to the development of these teachers' CK, PK, and CxK. One example of developing CK was when Irene reflected on getting a "refresher" on her content knowledge and how that increased her confidence in what she was teaching. Another example was when Kara spoke about realizing the possibilities for her students' learning when gaining an understanding of the 3D standards. Jane, along the same line of thought, spoke about how she thought she knew the standards, but that she realized that she "didn't even scratch the surface" of what 3D Learning and Teaching was and that after participation in the project she has been "able to feel comfortable" with 3D Learning and Teaching.

Related to PK, Kara, Jane, and Miranda spoke about shifting their thinking about pedagogy. For example, Miranda discussed moving beyond just content knowledge to "actually having content knowledge and knowing how students learn and putting it together. That it is more towards the way people learn. You learn by doing things." In relation to CxK, Miranda talked about knowing the rural area in which she taught. One obstacle for teachers taking on new reforms, such as 3D Learning and Teaching, occurs when they underestimate how much they will need to shift their practice (Spillane, Reiser, & Reimer, 2002). This suggests that it is important that teachers transitioning to 3D Learning and Teaching be provided opportunities to reflect on their practices in order to develop all areas of their 3D-PCK (Bertram, 2014).

Opportunities to understand 3D standards. Another important characteristic of effective PD is that the professional learning experience is tied to content knowledge and connected to the work of the teacher (Birman, Desimone, Porter, & Garet, 2000; Desimone & Garet, 2016; Garet et al., 2001). Although content is important, learning science content by itself does not allow teachers to apply what they learn to their teaching practices (Heller et al., 2012; Reiser, 2013). Effective PD centered on 3D Learning and Teaching and the 3D standards that guide this learning allows teachers to not only focus on the content (DCIs), but also focus on the modes (SEPs and CCCs) in which students will engage in sensemaking around the DCI in the context of their classrooms (National Research Council, 2012; Ravit, Krajcik, & Rivet, 2017; Reiser, 2013; Schwarz et al., 2017). Through this project, teachers identified that the opportunity to be able to gain understanding of the 3D standards helped them in transitioning to 3D Learning and Teaching. The participants described a range of understanding of the 3D standards including simply understanding the written format and what each part of the standards were, knowing in depth what each dimension was and how to use them in instruction, how to integrate the three dimensions into meaningful learning experiences, and how phenomena relate to the standards.

For many of these participants they had little previous experience with 3D standards as indicated in the quantitative data for RQ1. By providing the opportunity and time for teachers to gain understanding of what the 3D standards were and how to read them, the teachers were able to develop their

CK. By providing the opportunity for teachers to move beyond simply knowing how to read the standards to what each dimension entailed, how they work together, and how to integrate them to create meaningful science learning experiences for their students, the teachers were able to also increase their PK. Kara, Diana, Jane, Miranda, and Jill, for example, all indicated that knowing the standards made it easier to write instructional tasks and implement 3D Learning. Irene specifically discussed how knowing the standards allowed her to learn how to engage her students.

Opportunities for the teacher to be the learner. One of the internal support structures that participants identified as being most powerful for them was the opportunity to be a learner and experience 3D Learning from their students' perspective through the project. Professional development that involves active engagement in sensemaking and problem solving allows teachers to construct their own knowledge in much the same way that their students would in the classroom (Garet et al., 2001). This allows the teachers to have their own meaningful learning experiences and helps them to see how their students learn, making classroom application easier (Desimone & Garet, 2016; Garet et al., 2001; Reiser, 2013). As Irene phrased it the "not teaching", the discovery as a teacher was powerful for her as she stated, "as a teacher that puts you back in the student place and makes you remember what your students feel like." All of the participants mirrored this sentiment in some way. For example, Miranda reflected that is was the experience of doing 3D Learning in the project and the being able to try it out from a student perspective before trying it out in the classroom helped her develop her 3D Learning.

Based on these findings it appears that these teachers have developed their PK and CxK through the process of the teacher being the learner. As teachers see 3D Learning modeled and are able to take part in it they are able to see and experience the pedagogy related to 3D Learning. Additionally, as the teachers take the students' perspective, they are thinking about the students that they teach and are making contextual connections to their classrooms and their students (Appleton, 2008).

Opportunities for encouragement and belief in self. Another Internal Structure important to the participants and their growth in 3D Learning and Teaching centered on having the chance to be encouraged and believe in themselves as educators. Appleton (2008) during a study on PCK in elementary teachers found that improved self-confidence related strongly to teachers' ability to transfer practices focused on during PD to the classroom. This finding was seen for this study as well. The teachers related a sense of increased confidence in their ability to implement 3D Learning. This related most directly to helping develop the teachers' PK and secondly their CK as their confidence arose from their increase in understanding of 3D Learning and Teaching and how to implement 3D learning and teaching in their classrooms.

3D model and 3D instructional/assessment task format and instructional/assessment tasks database. As described in Chapter 3, the project utilized a 3D model and a specific evolving format for creating 3D instructional tasks for the teachers to utilize as they planned 3D Learning experiences for their students. The use of these structures served as both models and scaffolding for the teachers as they moved from experiencing 3D Learning to beginning to implement 3D Learning in their classrooms. These structures provided a framework to scaffold and focus the teachers' thinking as they planned instruction for 3D Learning experiences. For example, Kara stated, "It makes me sit down and literally think more carefully about how I'm teaching, why I'm teaching, and what I'm teaching." All of the participants reflections about having these structures to help them were similar, describing how the structure of the 3D instructional model and the 3D instructional task made them more intentional with what they were teaching their students. Additionally, having access to the Instructional/Assessment Task database provided the teachers with other 3D Learning experiences developed by their peers utilizing the scaffolded format to implement. Other studies that used some form of a scaffolding structure for teacher planning saw similar results (Jong & Valk, 2007; Otto & Everett, 2013). These scaffolding structures assist teachers in organizing their instruction and focus them on developing their 3D Learning and Teaching in a way that makes it easier for them translate it into the classroom (Loughran, Berry, & Mulhall, 2007). In this way these teachers appeared to more fully develop their PK and their CK.

Teaching resources and strategies. Through the project teachers were provided with various physical resources and teaching strategies to assist them in constructing and implementing 3D Learning experiences for their students.

Each of these resources allowed teachers to develop different aspects of their 3D-PCK depending on the focus of the resource. One resource was a printed color copy of the 3D standards in which each dimension of the standard had its own color. This helped teachers build their CK and PK as they used this resource to plan 3D Instructional Tasks (ITs). Teachers were also provided a frameworks resource which highlighted and bundled the PEs at their specific grade level and the common preconceptions that students have regarding the DCI concepts. This resource helped the teachers develop their CK and PK as it focused the teachers on the specific DCI concepts for their grade level and prepared them for the ideas that students have regarding those concepts. Teachers were also provided a NSTA resource book that broke down all the DCIs and explained the science content related to all the DCIs (Ravit et al., 2017). This resource helped teachers build their CK as they used it to review science content related to their grade level.

Teachers were also provided a full set of formative assessment probe books (Keeley, Eberle, and Farrin, 2005; Keeley, Eberle, and Tugel, 2007; Keeley, Eberle, and Dorsey, 2008; Keeley and Tugel, 2009). Teachers utilized these assessment books to elicit student thinking during implementing their 3D ITs. This resource allowed teachers to hone their PK as it helped them make instructional decisions before, during, and after implementation of a 3D IT. Teachers were also provided with a resource book focusing on formative assessment teaching strategies. During the PD many of these strategies were modeled for the teachers. This resource along with the strategies modeled provided an opportunity for teacher to develop their PK. A few of the teachers also mentioned one of the PD facilitators that was brought in during the summer workshop that focused on culturally relevant formative assessment and pedagogy. This resource and experience helped teachers develop their PK and CxK. Each of these resources gave opportunities for teachers to build different aspects of their 3D-PCK depending on how much they interacted with each as the planned and implemented 3D Learning and Teaching. One way that these resources can accomplish this is that they make relevant connections between the PD focused on 3D Learning and Teaching to the classroom and the teachers' own practice (Borko, Jacobs, & Koellner, 2010; Darling-Hammond & Richardson, 2009; Lampert, 2009; Putnam & Borko, 2000; Reiser, 2013).

Peer collaboration and project staff. The final structures that participants identified as central to helping them make the transition to 3D Learning and Teaching was the opportunity to collaborate with peers and project staff throughout the PD. Many of the teachers in the project were from smaller rural schools and often times were the only science teacher in their school building. The opportunity to collaborate with other teachers that were in the same process of transitioning to 3D Learning and Teaching helped the teachers to develop a more robust 3D-PCK. For example, Diana struggled with how to present phenomena to her students, but through peer collaboration she was able to get other perspectives that helped her work through that struggle and in doing so develop her PK regarding using phenomena. Miranda also developed her PK through getting to see other teachers implement 3D ITs and collaborate on debriefing the experience. Jill was able to develop her CK as she collaborated with peers to construct a larger personal database of phenomena to utilize with the DCI concepts at her grade level. These are a sample of ways in which teachers developed their 3D-PCK by engaging in peer collaboration focused on implementing 3D Learning and Teaching in their classrooms. Reiser (2013) suggested that PD needs to be structured so that teachers are working collaboratively to apply *NGSS* to their classroom for teachers to successfully make the transition to 3D Learning and Teaching. This is in line with other research regarding teacher learning (Desimone & Garet, 2016; Gabriel, Day, & Allington, 2011; Garet et al., 2001; Putnam & Borko, 2000; Wilson, 2013) and studies directly involving PCK that utilized collaboration (Hanuscin, Menon, & Lee, 2011; Juhler, 2016).

RQ3: Teachers' 3D-PCK translated into classroom instructional practices. Theme 1: Evidence of Growth, provided insight into the growth outcomes that teachers experienced as a result of the Growth Support Structures that helped teachers develop their 3D-PCK. These ideas serve as evidence for the growth that the participants experienced during Year One of the project and highlight ways in which the teachers' 3D-PCK was translated into their classroom instructional practices. Teachers' 3D-PCK was exhibited in multiple ways, from teachers shifting their practices from didactic, teacher-centered modes to explicit examples of 3D Learning implemented in the classroom. Three-Dimensional PCK was utilized as a lens to interpret the connections between Theme 1 and Theme 2 and provided a view of how the participants 3D-PCK development translated to the classroom. These connections are mapped in Figure 17 below. Each of the support structures for

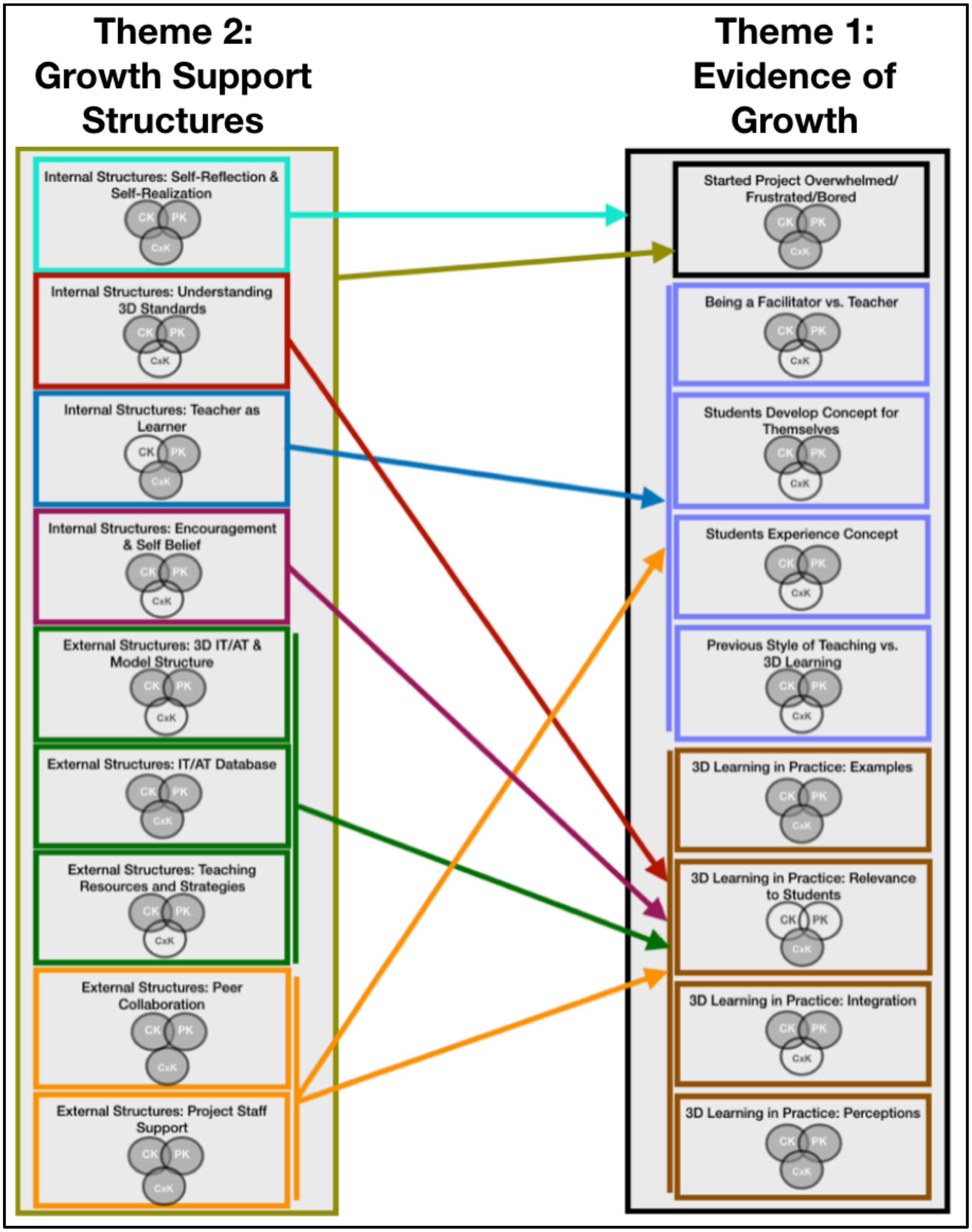


Figure 17. Mapping 3D-PCK Growth and Outcomes Between Theme 2 and Theme 1.

Theme 2: Growth Support Structures are displayed in the left column in the order presented in Chapter 4 and each of the evidences of growth identified in Theme 1: Evidence of Growth are displayed on the right in the order presented in Chapter 4. The color-coded boxes are meant to represent components that are grouped together such as the External Structures components in Theme 2: Growth Support Structures; the Being a Facilitator vs Teacher, Students Develop Concept for Themselves, Students Experience Concept, and Previous Style of Teaching vs. 3D Learning components of Theme 1: Evidence of Growth; and the 3D Learning in Practice components of Theme 1: evidence of Growth.

The arrows from the components of Theme 2: Growth Support Structures connect to the components of Theme 1: Evidence of Growth that have the strongest cause and effect relationship based on my analysis of the qualitative data for both of these themes. For example, all the components of Theme 2: Growth Support Structures relate to the teachers moving from a feeling of frustration at the beginning of the project to a feeling of confidence with 3D Learning at the end of the project. This is displayed as the light green box surrounding all the components of Theme 2 with the arrow pointing to the Started Project Overwhelmed/Frustrated/Bored component of Theme 1. Likewise, the Internal Structures: Self-Reflections and Self-Realization component of Theme 2 provided support for growth in all the components in Theme 1 as indicated by the light blue arrow pointing to the black box surrounding all of the components of Theme 1.

Additionally, the aspects of the participants' 3D-PCK that were developed in relation to each component are shaded. For example, with the Internal Structure: Self-Reflection and Self-Realization component of Theme 2, the participants developed their CK, PK, and CxK. Whereas, with the Internal Structures: Understanding 3D Standards component of Theme 2: Growth Support Structures, participants only developed their CK and PK. These connections and growth in 3D-PCK are discussed in the following section. This graphic was utilized as a tool to organize my thinking about the apparent connections between Theme 2: Growth Support Structures and Theme 1: Evidence of Growth. Theme 1: Evidence of Growth and the connections to Theme 2: Growth Support Structures are discussed in the following section.

One indicator of growth for the participants was that most participants described being overwhelmed starting the project, but by the end of the project they described being confident in their understanding of 3D Learning and Teaching. This increase in confidence level related to the teachers increasing in their understanding and implementation of 3D Learning and Teaching as previously discussed in RQ1 and RQ2 and as a result of all of the growth structures identified in Theme 2 (see Figure 17). This evidence suggests that the teachers have increased in all three aspects of their 3D-PCK (Bertram, 2014; Bertram & Loughran, 2012; Chordnork & Yuenyong, 2014; Hanuscin et al., 2011; Hume, 2010; McNeill & Knight, 2013; Van Driel, Verloop, & de Vos, 1998).

The way that these teachers' 3D-PCK translated into the classroom was shown in the way teachers described how their teaching has changed from before the project to after participating in the project. All of the participants described shifting their thinking about student learning and as a result, also their instructional practices. Four of the Evidence of Growth codes relate to this idea teachers made explicit comparisons about their teaching prior to the project compared to their teaching now, teachers described becoming more of a facilitator vs. a traditional teacher, teachers described instances when students developed the concept(s) for themselves, and teachers described instances when they planned for students to experience concepts instead of reading or hearing a lecture about them. These codes all relate to conceptual changes in the way that teachers think about how students learn and how best to plan for and carry out student learning experiences in their classroom.

These changes in these teachers' instructional practices signifies a shift from a didactic teaching orientation to an orientation of discovery and/or inquiry (Magnusson et al., 1999). In a sense they have shifted their purpose for teaching from transmitting knowledge to the students to a purpose more closely aligned the *Frameworks* (NRC, 2012) and the *NGSS* (Lead States, 2013) by providing opportunities for students to engage with and construct explanations for phenomena by engaging in the SEPs and CCCs and applying the DCIs. According to Demirdogen (2016), a teacher's purpose for science teaching determines the PCK aspects with which they engage and interact. As in this current study, as teachers shifted their purpose to be more student-centered and inquiry, they more fully developed their PK and CK. These instructional practice shifts and 3D-PCK development were most strongly supported by the opportunities during Year One for the teachers to engage as learners, the opportunity for collaboration with peers and project staff centered on implementing 3D Learning and Teaching, and the self-reflection and realizations that occurred as a result (see Figure 17).

Another evidence of teachers developing their 3D-PCK was shown in the descriptions of their implementation of 3D Learning and Teaching in their classrooms as presented in the participants' PaP-eRs. It is through these evidences that the conceptual changes that occurred in teachers thinking about students learning and science teaching are put into practice. Four codes were related to 3D Learning in Practice: described explicit examples of 3D Learning being implemented, described instances of teachers explicitly making relevant connections to students lives and experiences, described instances of 3D Learning integrating multiple concepts and/or disciplines, and teachers' described perceptions of 3D Learning in their classrooms. Each of these codes indicates the development of different aspects of teachers' 3D-PCK. Elements of CK, PK, and CxK can be exhibited in the examples and perceptions of 3D Learning provided by the teachers as they applied this type of learning and teaching into their classrooms.

The instances when teachers chose either phenomena or investigations that directly related to their students, such as with Jane, Miranda, and Jill, are evidence that these teachers are using their contextual knowledge of the students and community to make the science learning experience relevant and engaging. This is direct evidence that these teachers have developed their CxK in relation to 3D Learning. Some of the participants also described instances in which they were able to integrate other science content and/or subjects during 3D Learning implementation. All of the elementary teachers noted that they could easily integrate other subjects into the what they were doing with 3D Learning and Teaching. To some extent the secondary teachers were able to integrate other subjects, but more so they were able to integrate multiple DCI ideas within a series of 3D Learning experiences. These examples provide evidence that the teachers were able to develop their CK and their PK as integration would require a teacher to know their content well enough to coherently integrate it and the teacher would need the pedagogical skills to successfully bring the multiple ideas together into a meaningful learning experience.

The ability of teachers putting 3D Learning into practice in their classrooms shows that all the support structures served to help the participants develop a robust 3D-PCK and that the teachers were able to apply their 3D-PCK to their classrooms in ways that were successful (see figure 17). Other PCK studies have similarly found that teachers were able to develop and apply their PCK when participating in a PD consisting of a system of support (Chordnork & Yuenyong, 2014; Demirdöğen, 2016; Garritz, Labastida-Piña, Espinosa-Bueno, & Padilla, 2010; Hume, 2010; Loughran et al., 2007; Reiser, 2013; Van Driel et al., 1998; Wilson, 2013).

RQ5: Perceived outcomes resulting from participation in a 3D Learning-focused professional development program. Theme 3: Driving Motivation for Growth emerged unexpectedly as teachers described their thinking about 3D Learning and their reflections of implementing 3D Learning. These ideas focused in on the mechanisms that motivated these teachers to continue to develop their 3D-PCK and in another way are the outcomes of teachers continuing to transition to 3D Learning and Teaching. These motivations provided positive feedback to the participants, which strengthened and reinforced their efforts to transition to 3D Learning and Teaching and as a result continue to develop their 3D-PCK. Teachers seem to be increasingly having more demands placed on them and are finding teaching under these demands more cumbersome. Teachers in this project, through implementing 3D Learning, described teaching being fun again and that they were finding joy in this way of teaching.

Related to finding joy in teaching is that the participants were able to see success in their students (such as increased engagement, deeper understanding, and increased collaboration) through the implementation of 3D Learning and Teaching and seeing that success related to increased motivation (Heller et al., 2012). Additionally, teachers shared the sentiment that this style of teaching helped them to be the teacher that they really wanted to be, more of a facilitator that helped their students to be curious learners seeking answers. One byproduct of their implementation of 3D Learning was that they felt it made teaching much easier. This could be because as their students were increasingly engaged in the process of investigating and learning that classroom management would be less of an issue. Each of these ideas provided feedback to the teachers reinforcing their efforts to plan for and implement 3D Learning experiences for their students and as a direct result developing and their CK, PK, and CxK so that their PCK is becoming specialized toward 3D Learning and Teaching. These motivational feedbacks have been internalized due to the utility of 3D Learning and Teaching and served to increase the teachers' 3D-PCK (Ryan & Deci, 2000). These feedbacks are congruent with the Model of Professional Knowledge and Skill which includes PCK within the classroom practice and identifies student behaviors and outcomes as amplifiers for the teachers' beliefs, orientations and practices (Gess-Newsome, 2015).

Implications

There are several different implications of this study that can be made regarding PD focused on 3D Learning and Teaching, the utility of the 3D-PCK framework for researchers and practitioners, and the place of the 3D-PCK framework within the larger body of PCK research and within the realm of 3D Learning, respectively. This study focused on Year One of a PD project focusing on transitioning to 3D Learning and Teaching as outlined by the *Framework* (NRC, 2012) and the *NGSS* (NGSS Lead States, 2013).

The findings from this study can have relevant implications for PD programs with similar foci. Much like the recommendations for PD to support teachers transitioning to 3D Learning (Reiser, 2013), this current study found that many of these recommendations were successful in supporting teachers working toward realizing the *Framework* (NRC, 2012) and the *NGSS* (NGSS Lead States, 2013). The teachers in this study were able to develop aspects of their 3D-PCK through engaging in sustained PD that was directly related to the teachers' subject matter and classroom practice providing opportunities for teachers to reflect on their instructional practices and beliefs, involved active learning so that the teachers had the opportunity to be the learner, had "high pay-off" in the classroom so that teachers saw success with 3D Learning and Teaching, was a part of a system of support with relevant resources and strategies for implementing 3D Learning and Teaching, and is collaborative in nature so that teachers are working together to enact the reform (Appleton, 2008; Gabriel et al., 2011; Hanuscin et al., 2011; National Academies of Sciences, 2015; Reiser, 2013). Other professional development programs can take these findings into consideration when planning and facilitating reform-based teacher professional learning.

The 3D-PCK framework proved useful in this study as a tool for identifying areas of teacher knowledge related to 3D Learning and Teaching. This allowed the researcher to gain insight into teacher knowledge of 3D Learning and Teaching and how the components that make up their 3D-PCK were translated into their classrooms. PCK has been a powerful construct for uncovering the tacit knowledge and thinking behind a teacher's decisions and practice (Kind, 2009; Shulman, 2015). By placing PCK within the context of 3D Learning and Teaching as outlined by the *Framework* (NRC, 2012), teachers' hidden knowledge and educational philosophies regarding 3D Learning and Teaching can rise to the surface for both researchers and the teachers themselves to utilize (Gess-Newsome, 2015). As many states are in the process of transitioning to 3D science standards (National Science Teachers Association, 2018) the 3D-PCK framework could be a useful tool for teachers as they make shifts in their instructional practices as well by the administrators and PD facilitators supporting these teachers.

Three-Dimensional PCK exists within a much larger body of knowledge about teachers' PCK (Gess-Newsome, 1999, 2015; Gess-Newsome & Lederman, 2002; Magnusson et al., 1999; Shulman, 1986, 2015). The 3D-PCK framework utilized in this study applies the ideas surrounding PCK and sets them explicitly in the context of 3D Learning. Researchers that are examining 3D Learning and the various ways this reform is being implemented could utilize 3D-PCK to identify how teachers' thinking about, planning for, and implementation of 3D Learning is changing and developing through the process of adopting 3D Learning practices. In this study, 3D-PCK was examined through the planning and implementation of 3D Learning in the classroom. The findings from this study are congruent with the model of TPK&S where PCK is placed within classroom practice (Gess-Newsome, 2015). Likewise, the 3D-PCK model and the findings of this study are also compatible with the teaching orientations presented in the Magnussen et al. (1999) PCK model. The 3D-PCK model used in this study relates directly to the PCK model put forth by Gess-Newsome (1999). PCK research has spent many years in the realm of academic research and little time within the practical world of the classroom teacher (Kind, 2009). Additionally, there are no current common ways to examine how teachers are encouraged to develop their PCK related to 3D Learning (NASEM, 2015). By using this simplified PCK framework to focus specifically on PCK related to 3D Learning the components have been redefined to better describe the CK, PK, and CxK that most directly relates to 3D Learning as outlined by the *Framework* (NRC, 2012). My hope is that the 3D-PCK framework will be recognized for its utility to researchers, teachers, and PD facilitators to examine and document the specialized knowledge of science teachers as they move toward fully realizing 3D Learning and Teaching.

Limitations

This study investigated teachers' PCK in a three-year, 3D Learning context-centered professional development program by capturing their understanding of 3D Learning and Teaching as they were in the process of transitioning to 3D instruction. Several possible limitations existed within this study and the underlying framework. The participants in this study only represented rural schools. As a result, the findings from this study should be viewed through that context in their interpretation and applicability to other contexts. Future studies should include a more diverse group of teachers who would represent more diverse school populations. This study sought to understand PCK in a 3D context; however, 3D-PCK might emerge differently and have different characteristics if observed in a project that includes teachers from larger school districts and in different cultural contexts. It is recommended to include teachers from suburban and urban school settings for future studies.

Additionally, the field of participants in the project chose to take part in the professional development. This could mean that these teachers are more willing to change their teaching practices than teachers that did not choose to participate in the project. From this group of teachers, the participants for this study were selected as a convenience sample. Because the teachers in this research study agreed to take part in this study, this might also indicate their additional willingness to change their teaching practice. As the ability to generalize findings in a “statistical sense cannot occur in qualitative research” findings from a qualitative study can provide information that can be relevant to other similar cases (Merriam, 2009, p. 224; Stake, 1995). As such, those using the findings from this study need to be aware that the information learned about PCK in a 3D Learning context from this study can only directly represent the group of individuals and the project from which these findings emerged. Those attempting to utilize these findings will need to be cautious when attempting to make application of 3D-PCK as it was described in this study.

Another limitation centers on me, the researcher. In this study, I was also the professional development facilitator through the course of the project. This removes some of the objectivity for me as the researcher as I played a major role in the development of teacher knowledge and pedagogy in the project. The closeness and relationships with the participants could have influenced how I interpreted the data. To help alleviate this influence in this study, I relied on other research professionals within the field of 3D Learning as well as the external evaluator for the project to provide triangulation to strengthen the validity of the interpretations and findings found within this particular study. Additionally, the researcher employed the use of bracketing to suspend any possible bias or preconceived ideas when collecting and analyzing data for this study (Garfinkel, 1967; Gubrium & Holstein, 1997).

Strengths

Despite the possible limitations associated with this study, strengths were built into the underlying design. This study investigated Year 1 of a three-year project focused on phenomena driven 3-D Learning and Teaching. Multiple types of data, both quantitative and qualitative, from this project were collected. The length of the study provided multiple opportunities to collect various forms of data at different times of the project; this allowed me as the researcher to triangulate using multiple data points and types of data further increasing the internal validity (Merriam, 2009). The varied amount and types of data were a rich resource utilized to inform the study and thus provided a more complete understanding of 3D-PCK within the context of this study. Also, teachers were able to participate in multiple professional development experiences thereby providing further opportunities for participants to develop their understanding of 3D Learning and Teaching. Additionally, this study took place in the context of a teacher-centered, sustained professional development project focused on learning and teaching that was directly relevant for the participants. Effective professional learning for teachers extends over time, is embedded in the work of the teachers, and promotes refection and inquiry (Birman et al., 2000; Desimone & Garet, 2016; Desimone, Porter, Garet, Yoon, & Birman, 2002).

Directions for Future Research

3D-PCK could be a valuable tool for practicing teachers, administrators, and curriculum coordinators, as well as, for teacher preparation programs. Shulman, along with others, has argued that studying the relationships between teacher cognitive understanding and how it is expressed in classroom instruction could be the “missing program in educational research” (Gess-Newsome, 1999; National Academies of Sciences, 2015). Practicing classroom teachers have the benefit of experience, which is a critical aspect of PCK growth (Gess-Newsome, 1999). However, as practicing teachers adapt to changing reforms and requirements, new forms and adaptations of PCK may be required. Three-Dimensional PCK could serve as a tool for educators and those supporting them as they implement new reforms in their classrooms. Future research could explore the use of 3D-PCK as a reflective tool for teachers to identify their own PCK related to 3D Learning and Teaching as they shift their practices toward 3D Learning. Research could also be conducted to determine the effectiveness of the 3D-PCK framework to identify and document the growth of 3D-PCK in teachers’ settings different from this current study and how that information could be useful for individuals that are supporting these shifts.

Additionally, new teachers entering the classroom will need the proper pedagogical content knowledge to be successful in their future classrooms. Research might look at how the 3D-PCK framework could be explicitly taught in teacher preparation programs and how pre-service teachers, who do not have the experience of practicing teachers, can develop 3D-PCK to better prepare them for the science classroom. This is a challenge for science teacher preparation programs as most prospective teacher preparation programs have “done little to develop an *explicit* knowledge of practices in the framework or the associated procedural and epistemic knowledge” (Osborne, 2014, p. 192). Teacher preparation programs are starting to begin to integrate 3D Learning and Teaching into their courses. Researchers could utilize the new PCK model (Gess-Newsome, 2015) along with the 3D-PCK utilized as the framework for this study to extend, document, and measure the development of 3D-PCK in both pre-service teacher and practicing classroom teachers. This could lead to the next generation of science education being led by science educator professionals who are fully equipped to facilitate deeper understanding of science concepts in their students via their understanding and utilization of 3D-PCK.

Conclusion

This study examined the PCK of teachers as they transitioned to new reforms in science education during Year One of a long-term 3D Learning-focused PD. Teachers in this project showed increased understanding and confidence with 3D Learning as well as an increase in the implementation of 3D Learning and Teaching in their classrooms. The proposed 3D-PCK model was utilized to investigate teachers’ beliefs and practices regarding 3D Learning and Teaching. Through this project, teachers were successful in developing robust

CK, PK, and CxK related to 3D Learning and Teaching. The teachers in this project identified the experiences and structures that helped them to develop their 3D-PCK as well as support them as they translated their 3D-PCK into the classroom through their instructional practices. As a result of having these experiences these teachers were able to describe how they have changed as a teacher and what motivated them during and after their transition to 3D Learning and Teaching. The 3D-PCK model proved to be a useful framework for bridging the gap between PCK and 3D Learning and Teaching, bringing these two areas of study together to make PCK more accessible for the next generation of science education.

References

Abell, S. K. (2007). Research on science teacher knowledge. In S. K. Abell & N.G. Lederman (Eds.), *Handbook of research on science education* (pp. 1105-1149). New York: Routledge.

Achieve. (2016). *Using phenomena in NGSS-designed lessons and units*. Next Generation Science Standards Retrieved from http://www.nextgenscience.org/sites/default/files/Using%20Phenomena%20in%20NGSS.pdf.

Adams, P. E., & Krockover, G. H. (1997). Concerns and perceptions of beginning secondary science and mathematics teachers. *Science Education, 81*(1), 29-50.

Allen, C. D., & Penuel, W. R. (2015). Studying teachers' sensemaking to investigate teachers' responses to professional development focused on new standards. *Journal of Teacher Education, 66*(2), 136-149.

Alvarado, C., Garritz, A., & Mellado, V. (2015). Canonical pedagogical content knowledge by CoRes for teaching acid–base chemistry at high school. *Chemistry Education Research and Practice, 16*(3), 603-618.

Appleton, K. (2008). Developing science pedagogical content knowledge through mentoring elementary teachers. *Journal of Science Teacher Education, 19*(6), 523-545.

Aydin, S., & Boz, Y. (2012). Review of studies related to pedagogical content knowledge in the context of science teacher education: Turkish case. *Educational Sciences: Theory and Practice, 12*(1), 497-505.

Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching what makes it special? *Journal of Teacher Education, 59*(5), 389-407.

Banilower, E. R., Smith, P. S., Weiss, I. R., Malzahn, K. A., Campbell, K. M., & Weis, A. M. (2013). *Report of the 2012 national survey of science and mathematics education.* Chapel Hill, NC: Horizon Research, Inc.

Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The Qualitative Report, 13*(4), 544-559.

Berry, A., Friedrichsen, P., & Loughran, J. (Eds.). (2015). *Re-examining pedagogical content knowledge in science education*. New York: Routledge.

Berry, A., Loughran, J., & van Driel, J. H. (2008). Revisiting the roots of pedagogical content knowledge. *International Journal of Science Education, 30*(10), 1271-1279.

Bertram, A. (2014). CoRes and PaP-eRs as a strategy for helping beginning primary teachers develop their pedagogical content knowledge. *Educación Química, 25*(3), 292-303.

Bertram, A., & Loughran, J. (2012). Science teachers' views on CoRes and PaP-eRs as a framework for articulating and developing pedagogical content knowledge. *Research in Science Education, 42*(6), 1027-1047.

Birman, B. F., Desimone, L., Porter, A. C., & Garet, M. S. (2000). Designing professional development that works. *Educational leadership, 57*(8), 28-33.

Borko, H., Jacobs, J., & Koellner, K. (2010). Contemporary approaches to teacher professional development. In P. Peterson, E. Baker, & B. McGaw (Eds.), *International encyclopedia of education, 7* (pp.548-556). Oxford: Elsevier

Bybee, R. W., & Sund, R. B. (1982). *Piaget for educators*. Prospect Heights, IL: Waveland Press.

Bybee, R. W. (2013). *Translating the NGSS for classroom instruction*: Arlington, VA: NSTA Press.

Capps, D. K., & Crawford, B. A. (2013). Inquiry-based instruction and teaching about nature of science: Are they happening? *Journal of Science Teacher Education, 24*(3), 497-526.

Chordnork, B., & Yuenyong, C. (2014). Constructing CoRe as a methodological for capturing pedagogical content knowledge: A case study of Thailand teachers teaching global warming. *Procedia-Social and Behavioral Sciences, 116*, 421-425.

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches*. Thousand Oaks, CA: Sage.

Creswell, J. W., & Clark, V. L. P. (2007). *Designing and conducting mixed methods research* (Vol. 2). Thousand Oaks, CA: Sage.

Creswell, J. W., & Clark, V. L. P. (2018). *Designing and conducting mixed methods research* (Vol. 3). Thousand Oaks, CA: Sage.

Daehler, K. R., Heller, J. I., & Wong, N. (2015). Supporting growth of pedagogical content kowledge in science education. In A. Berry, P.

Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp.45-59). New York: Routledge.

de Jong, O., van Driel, J. H., & Verloop, N. (2005). Preservice teachers' pedagogical content knowledge of using particle models in teaching chemistry. *Journal of Research in Science Teaching, 42*(8), 947-964.

Demirdöğen, B. (2016). Interaction between science teaching orientation and pedagogical content knowledge components. *Journal of Science Teacher Education*, 27(5), 495-532.

Desimone, L. M., Porter, A. C., Garet, M. S., Yoon, K. S., & Birman, B. F. (2002). Effects of professional development on teachers' instruction: Results from a three-year longitudinal study. *Educational Evaluation and Policy Analysis, 24*(2), 81-112.

Desimone, L. M., & Garet, M. S. (2016). Best practices in teachers' professional development in the United States. *Psychology, Society, & Education, 7*(3), 252-263.

Friedrichsen, P., Driel, J. H. V., & Abell, S. K. (2011). Taking a closer look at science teaching orientations. *Science Education, 95*(2), 358-376.

Gabriel, R., Day, J. P., & Allington, R. (2011). Exemplary teacher voices on their own development. *Phi Delta Kappan, 92*(8), 37-41.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results froms a national sample of teachers. *American Educational Research Journal, 38*, 915-945.

Garfinkel, H. (1967). *Studies in ethnomethodology*. Englewood Cliffs, NJ: Prentice-Hall.

Garritz, A., Labastida-Piña, D. V., Espinosa-Bueno, S., & Padilla, K. (2010). Pedagogical content knowledge of inquiry: An instrument to document it and its application to high school science teachers. *Proceedings of the National Association of Research in Science Teaching Annual International Conference, Philadelphia, PA,* 20-24.

George, A. A., Hall, G. E., Stiegelbauer, S. M., & Litke, B. (2008). *Measuring implementation in schools: The stages of concern questionnaire*. Austin, TX: Southwest Educational Development Laboratory.

Gess-Newsome, J. (1999). Pedagogical content knowledge: An introduction and orientation. In J. Gess-Newsome & N. G. Lederman (Eds*.), Examining* *pedagogical content knowledge* (pp. 3-17). Dordrecht, The Netherlands: Kluwer.

Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 28-42). New York/London: Routledge.

Glaser, B., & Strauss, A. (1967). *The discovery of grounded theory: Strategies for qualitative inquiry.* Chicago, IL: Aldin.

Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education*. New York, NY: Teachers College Press.

Gubrium, J. F., & Holstein, J. A. (1997). *The new language of qualitative method*. Oxford, UK: Oxford University Press.

Guskey, T. R. (1999). Moving from means to ends. *Journal of Staff Development, 20*(1).

Guskey, T. R. (2002). Professional development and teacher change. *Teachers and Teaching: Theory And Practice, 8*(3), 381-391.

Hanuscin, D. L., Menon, D., & Lee, E.J. (2011). Developing PCK for teaching teachers through a mentored internship in teacher professional development. *Learning, Teaching, and Curriculum presentations (MU).*

Hayes, K. N., Lee, C. S., DiStefano, R., O'Connor, D., & Seitz, J. C. (2016). Measuring science instructional practice: A survey tool for the age of NGSS. *Journal of Science Teacher Education, 27*(2), 137-164.

Heller, J., Daehler, K., Shinohara, M., & Kaskowitz, S. (2004). *Fostering pedagogical content knowledge about electric circuits through case-based professional development.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, Vancouver, Canada.

Heller, J. I., Daehler, K. R., Wong, N., Shinohara, M., & Miritrix, L. W. (2012). Differential effects of three proffessional development models on teacher knolwledge and student achievment in elementary science. *Journal of Research in Science Teaching, 49*(3), 333-362. doi:10.1002/tea.21004

Hume, A. C. (2010). A pedagogical tool for science teacher education: Content representation (CoRe) design. *Science Teacher Education, 59,* 29-38.

Hunter, M., & Agranoff, R. (2008). *Metro high school: An emerging STEM school community*. Columbus, OH: PAST Foundation & Battelle Center.

Jong, O., & Valk, A. V. D. (2007). Science teachers' PCK and teaching practice: Learning to scaffold students' open-inquiry learning. In R. Pinto & D. Couso (Eds.), *Contributions from science education research* (pp. 107-118). New York: Springer.

Juhler, M. V. (2016). The use of lesson study combined with content representation in the planning of physics lessons during field practice to develop pedagogical content knowledge. *Journal of Science Teacher Education*, 27(5), 533-553.

Jüttner, M., & Neuhaus, B. J. (2013). Validation of a paper-and-pencil test instrument measuring biology teachers' pedagogical content knowledge by using think-aloud interviews. *Journal of Education and Training Studies, 1*(2), 113-125.

Keeley, P., Eberle, F., & Dorsey, C. (2008). *Uncovering student ideas in science: Another 25 formative assessment probes* (Vol. 3). Arlington, VA: NSTA Press.

Keeley, P., Eberle, F., & Farrin, L. (2005). *Uncovering student ideas in science: 25 Formative assessment probes* (Vol. 1). Arlington, VA: NSTA Press.

Keeley, P., Eberle, F., & Tugel, J. (2007). *Uncovering student ideas in science: 25 More formative assessment probes* (Vol. 2). Arlington, VA: NSTA Press.

Keeley, P., & Tugel, J. (2009). *Uncovering student ideas in science: 25 New formative assessment probes* (Vol. 4). Arlington, VA: NSTA Press.

Kind, V. (2009). Pedagogical content knowledge in science education: Perspectives and potential for progress. *Studies in Science Education, 45*(2), 169-204.

Kirschner, S., Borowski, A., Fischer, H. E., Gess-Newsome, J., & von Aufschnaiter, C. (2016). Developing and evaluating a paper-and-pencil test to assess components of physics teachers' pedagogical content knowledge. *International Journal of Science Education, 38*(8), 1343-1372.

Krajcik, J. (2015). Three-dimensional instruction. *The Science Teacher, 82*(8), 50.

Kuhn, T. (1970). *The nature of scientific revolutions*. Chicago, IL: Chicago University Press.

Lampert, M. (2009). Learning teaching in, from, and for practice: What do we mean? *Journal of Teacher Education, 61*(1-2), 21-34. doi:10.1177.0022487109347321

Lee, O., Miller, E. C., & Januszyk, R. (2014). Next generation science standards: All standards, all students. *Journal of Science Teacher Education, 25*(2), 223-233. doi:10.1007/s10972-014-9379-y

Lewis, C., Perry, R., & Murata, A. (2006). How should research contribute to instructional improvement? The case of lesson study. *Educational Researcher, 35*(3), 3-14.

Loucks-Horsley, S., Stiles, K. E., Mundry, S., & Hewson, P. W. (2009). *Designing professional development for teachers of science and mathematics*. Thousand Oaks, CA: Corwin.

Loughran, J., Berry, A., & Mulhall, P. (2007). Pedagogical content knowledge: What does it mean to science teachers?. In R. Pinto & D. Couso (Eds.), *Contributions from science education research* (pp. 93-105). Dordrecht: Springer.

Loughran, J., Berry, A., & Mulhall, P. (2012). *Understanding and developing science teachers' pedagogical content knowledge* (2nd ed.) Rotterdam, The Netherlands: Sense Publishing.

Loughran, J., Milroy, P., Berry, A., Gunstone, R., & Mulhall, P. (2001). Documenting science teachers' pedagogical content knowledge through PaP-eRs. *Research in Science Education, 31*(2), 289-307.

Loughran, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching, 41*(4), 370-391.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The constructs and implication for science education* (pp. 95-132). Dordrecht, The Netherlands: Kluwer.

Marek, E. A. (2008). Why the learning cycle? *Journal of Elementary Science Education, 20*(3), 63-69.

Marek, E. A., & Cavallo, A. M. (1997). *The learning cycle: Elementary school science and beyond* (Rev. ed.). Portsmouth, NH: Heinemann.

McNeill, K. L., & Knight, A. M. (2013). Teachers' pedagogical content knowledge of scientific argumentation: The impact of professional development on K–12 teachers. *Science Education, 97*(6), 936-972.

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation*. San Francisco, CA: Jossey-Bass.

Moulding, B., Bybee, R., Paulson, N., & Pruitt, S. (2015). *A vision and plan for science teaching and learning: An educator's guide to a framework for k-12 science education, next generation science standards, and state science standards*. Utah, NV: Essential Teaching & Learning.

National Academies of Sciences, Engineering, and Medicine. (2015). *Science teachers' learning: Enhancing opportunities, creating supportive contexts.* doi.org/10.17226/21836.

National Association of State Boards of Education. (2018). *Next generation science standards.* Retrieved January 10, 2018 from http://www.nasbe.org/project/next-generation-science-standards/

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

National Research Council. (2015). *Guide to implementing the next generation science standards*. Washington, DC: The National Academies Press.

National Science Teachers Association. (2018). *About the next generation science standards*. Retrieved January 10, 2018 from http://ngss.nsta.org/About.aspx

Newmann, F. M., Bryk, A. S., & Nagaoka, J. K. (2001). *Authentic intellectual work and standardized tests: Conflict or coexistence? Improving Chicago's Schools*. Chicago, IL: Consortium on Chicago School Research

Newmann, F. M., King, M. B., & Carmichael, D. L. (2007). Authentic instruction and assessment: Common standards for rigor and relevance in teaching academic subjects. *Des Moines, IA: Iowa Department of Education. Retrieved June, 24*(24), 2011.

Newmann, F. M., Marks, H. M., & Gamoran, A. (1995). Authentic pedagogy: Standards that boost student performance. *Issues in Restructuring Schools, 8*(Spring), 16.

Newmann, F. M., Secada, W. G., & Wehlage, G. (1995). *A guide to authentic instruction and assessment: Vision, standards and scoring*. Madison, WI: Wisconsin Center for Education Research Madison.

Newmann, F. M., & Wehlage, G. G. (1993). Five standards of authentic instruction. *Educational Leadership, 50*(7), 8-12.

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

Nilsson, P. (2008). Teaching for understanding: The complex nature of pedagogical content knowledge in pre‐service education. *International Journal of Science Education, 30*(10), 1281-1299.

Osborne, J. (2014). Teaching scientific practices: Meeting the challenge of change. *Journal of Science Teacher Education, 25*(2), 177-196.

Otto, C. A., & Everett, S. A. (2013). An instructional strategy to introduce pedagogical content knowledge using venn diagrams. *Journal of Science Teacher Education, 24*(2), 391-403.

Park, S., & Suh, J. K. (2015). From portraying toward assessing PCK: Drivers, dilemmas, and directions for future research. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 104-119). New York: Routledge

Passmore, C. M., & Svoboda, J. (2012). Exploring opportunities for argumentation in modelling classrooms. *International Journal of Science Education, 34*(10), 1535-1554.

Poon, C.-L., Lee, Y.-J., Tan, A.-L., & Lim, S. S. (2012). Knowing inquiry as practice and theory: Developing a pedagogical framework with elementary school teachers. *Research in Science Education, 42*(2), 303-327.

Pringle, R. M., Dawson, K., & Ritzhaupt, A. D. (2015). Integrating science and technology: Using technological pedagogical content knowledge as a framework to study the practices of science teachers. *Journal of Science Education and Technology, 24*(5), 648-662.

Printy, S. M., & Marks, H. M. (2004). Communities of practice and teacher quality. In W. Hoy & C. Miskel (Eds.), *Educational administration, policy and reform: Research and measurement. Research and Theory in Educational Administration* (pp. 91-122). Greenwich, CT: Information Age.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about researchon teacher learning? *Educational Researcher, 29*, 4-15.

Ravit, G. D., Krajcik, J., & Rivet, A. (2017). *Disciplinary core ideas: Reshaping teaching and learning*. Arlington, VA: NSTA Press.

Reiser, B. J. (2013). *What professional development strategies are needed for successful implementation of the next generation science standards.* Paper presented at the Invitational Research Symposium on Science Assessment (Vol. 24, p. 25).

Rowan, B., Schilling, S. G., Ball, D. L., Miller, R., Atkins-Burnett, S., Camburn, E., Harrison, D., & Phelps, G. (2001). *Measuring teachers' pedagogical content knowledge in surveys: An exploratory study*. Philedelphia, PA: Consortium for Policy Research in Education.

Ryan, R. M., & Deci, E. L. (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology, 25*, 54-67.

Schiro, M. S. (2013). *Curriculum theory: Conflicting visions and enduring concerns*. Thousand Oaks, CA: Sage.

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

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-23.

Shulman, L. S. (2015). PCK: Its genesis and exodus. In A. Berry, P. Friedrichsen & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 3-13). New York/ London: Routledge.

Slater, J. (2017). *An exploration of teacher autonomy in relation to elementary teachers' science instructional practice.* (Doctoral Dissertation) University of Oklahoma, Norman, OK.

Spillane, J. P., Reiser, B. J., & Reimer, T. (2002). Policy and implementation and cognition: Reframing and refocusing implementation research. *Review of Educational Research, 72*(3), 387-431.

Stake, R. E. (1995). *The art of case study research*. Thousand Oaks, CA: Sage.

Tosunoglu, C. H., & Lederman, N. G. (2016). *The development of an instrument for assessing pedagogical content knowledge for socioscientific knowledge (PCK-SSI)*. Paper presented at the National Association for Research in Science Teaching, Baltimore, MD.

Trygstad, P. J., Smith, P. S., Banilower, E. R., & Nelson, M. M. (2013). *The status of elementary science education: Are we ready for the next generation science standards?* Chapel Hill, NC: Horizon Research, Inc.

Turner, D. P. (2011). *Long-term impact of undergraduate science reform courses on the pedagogical content knowledge of kindergarten through sixth grade inservice teachers*. (Unpublished doctoral dissertation). University of Alabama, Tuscaloosa, AL.

University of Michigan. (2011). International center for the advancement of scientific literacy. Retrieved from http://www.icasl.org/

van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35*(6), 673-695.

Wilson, S. M. (2013). Professional development for science teachers. *Science, 340*(6130), 310-313.

Yin, R. K. (2010). *Qualitative research from start to finish*. New York, NY: Guilford Press.

Appendices

Appendix A: IRB Approval Letter

The UNIVERSITY of OKLAHOMA

Institutional Review Board for the Protection of Human Subjects

Approval of Initial Submission – Expedited Review – AP01

Date: April 28, 2016

IRB#: 6801

Principal Investigator: Linda K Atkinson, PHD

Approval Date: 04/28/2016

Expiration Date: 03/31/2017

Study Title: Central Oklahoma Rural Partnership for Science (CORPS)

Expedited Category: 6 & 7

Collection/Use of PHI: No

On behalf of the Institutional Review Board (IRB), I have reviewed and granted expedited approval of the above-referenced research study. To view the documents approved for this submission, open this study from the *My Studies* option, go to *Submission History*, go to *Completed Submissions* tab and then click the *Details* icon.

As principal investigator of this research study, you are responsible to:

- Conduct the research study in a manner consistent with the requirements of the IRB and federal regulations 45 CFR 46.
- Obtain informed consent and research privacy authorization using the currently approved, stamped forms and retain all original, signed forms, if applicable.
- Request approval from the IRB prior to implementing any/all modifications.
- Promptly report to the IRB any harm experienced by a participant that is both unanticipated and related per IRB policy.
- Maintain accurate and complete study records for evaluation by the HRPP Quality Improvement Program and, if applicable, inspection by regulatory agencies and/or the study sponsor.
- Promptly submit continuing review documents to the IRB upon notification approximately 60 days prior to the expiration date indicated above.
- Submit a final closure report at the completion of the project.

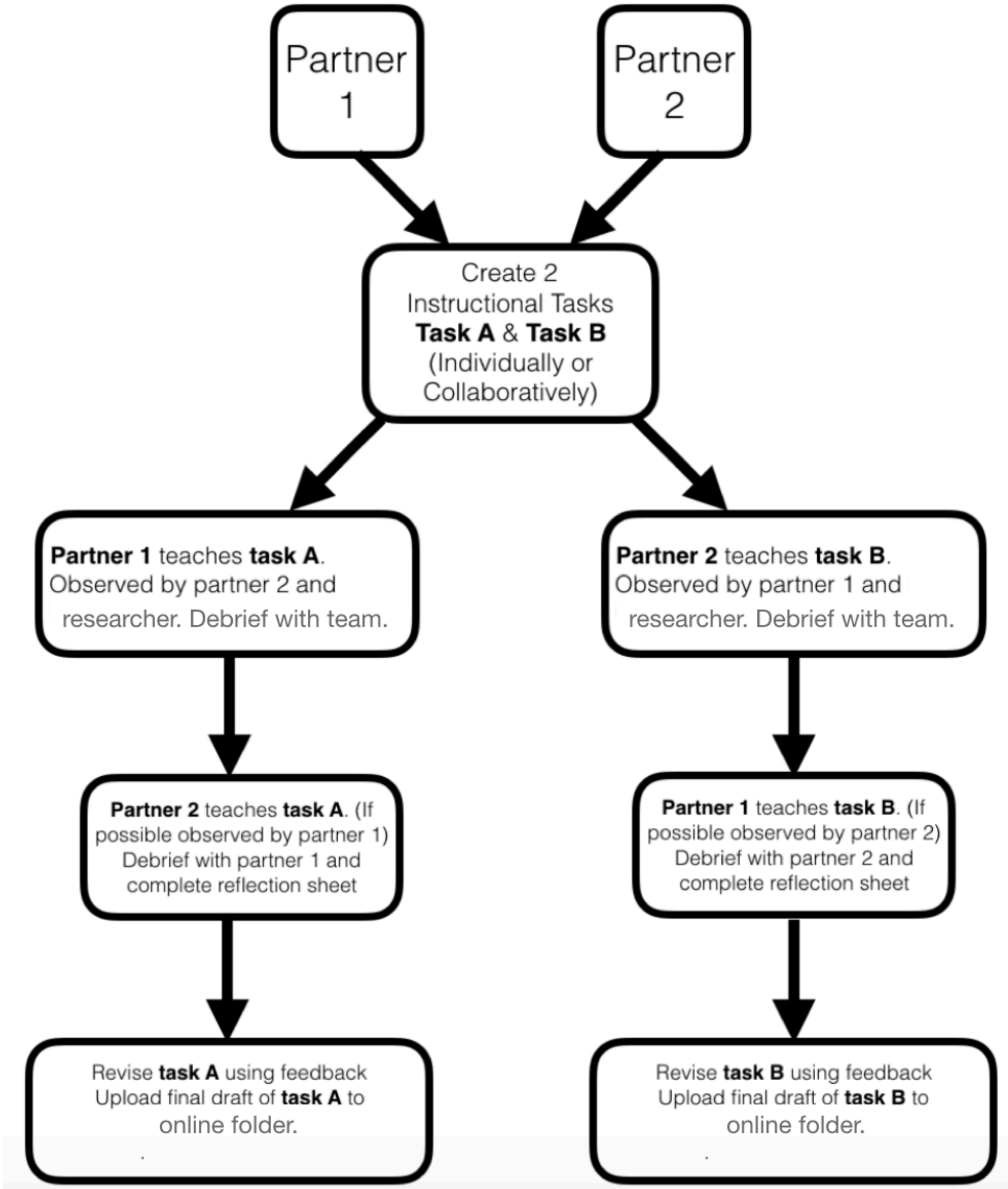
If you have questions about this notification or using iRIS, contact the IRB @ 405-325-8110 or irb@ou.edu.

Cordially,

Aimee Franklin, Ph.D.
Chair, Institutional Review Board

Appendix B: Modified Lesson Plan Outline

Instructional Tasks Development and Debrief Outline



Appendix C: Teacher Needs Assessment

Start of Block: Default Question Block

Q1
Central Oklahoma Rural Partnership for Science (CORPS)
Math Science Partnership
Needs Assessment

Please take a moment to complete the following questions.

Q2 How would you rate your experience level in regards to the new Oklahoma Academic Standards for Science (OAS-S)?

- ○ Newcomer (1)
- ○ Intermediate (2)
- ○ Moderate (3)
- ○ Advanced (4)
- ○ Expert (5)

Q3 Please rate your understanding for each of the following regarding the new Oklahoma Academic Standards for Science (OAS-S). To select the rating drag the dot to the appropriate number level.

Low						High				
0	1	2	3	4	5	6	7	8	9	10

Q3.1 Standards Format/Structure (1)	
Q3.2 Science and Engineering Practices (SEPs) (2)	
Q3.3 Disciplinary Core Ideas (DCIs) (3)	
Q3.4 Crosscutting Concepts (CCCs) (4)	
Q3.5 Performance Expectations (PEs) (5)	
Q3.6 Three Dimensions (6)	

Q4 What is your level of confidence in implementing the new Oklahoma Academic Standards for Science (OAS-S)? To select the rating drag the dot to the appropriate number level.

	Low	Medium	High
	0 1 2 3	4 5 6 7	8 9 10
Confidence Level (1)			

Q5 Please explain why you feel this way?

Q6 Describe your understanding of the similarities and differences between the PASS standards for Science and the new Oklahoma Academic Standards for Science (OAS-S).

Q7 Please briefly describe what type of training, information, or experiences would be helpful for you as a teacher in transitioning and implementing the new Oklahoma Academic Standards for Science (OAS-S).

End of Block: Default Question Block

Appendix D: Teacher Perception Survey

Start of Block: Default Question Block

This research has been approved by the University of Oklahoma, Norman Campus IRB.
IRB Number: 6801 Approval date: 08-23-2016

Q1

CORPS

Central Oklahoma Rural Partnership For Science

Q2
Please take a moment to complete the following questions.

Q3 Participant ID Number - The initial of your last name followed by the last four digits of your SSN.

____

Q4 Gender:

- ○ Male (1)
- ○ Female (2)

Q5 What is the name of your school district?

____

Q6 ELEMENTARY TEACHERS ONLY
Which of the following grades will you teach in the <u>upcoming</u> school year?

- ☐ K (1)
- ☐ 1st (2)
- ☐ 2nd (3)
- ☐ 3rd (4)
- ☐ 4th (5)
- ☐ 5th (6)
- ☐ 6th (7)
- ☐ Other (8) ____

Q7 ELEMENTARY TEACHERS ONLY

Which of the following subjects will you teach in the <u>upcoming</u> school year? (Check all that apply)

- ☐ Language Arts (Includes Reading) (1)
- ☐ Social Studies (2)
- ☐ Mathematics (3)
- ☐ Science (4)

Q8 MIDDLE AND HIGH SCHOOL TEACHERS ONLY

Which of the following grades will you teach in the upcoming school year?

- ☐ 5th (1)
- ☐ 6th (2)
- ☐ 7th (3)
- ☐ 8th (4)
- ☐ 9th (5)
- ☐ 10th (6)
- ☐ 11th (7)
- ☐ 12th (8)
- ☐ Other (9) ____

Q9 MIDDLE AND HIGH SCHOOL TEACHERS ONLY
Which of the following science classes will you teach in the upcoming school year? (Check all that apply)

- ☐ Physical Science (1)
- ☐ Biology 1 (2)
- ☐ Environmental Science (3)
- ☐ Chemistry (4)
- ☐ Physics (5)
- ☐ Other Science Class (6) ____

Q10 How many years have you been teaching altogether in grades K-12?

____

Q11 How many of those years have you taught science?

____

Q12 Have you participated in any other workshops that featured the new Oklahoma Academic Standards for Science (OAS-S)?

- ○ Yes (1)
- ○ No (2)

Q13 Please indicate your highest earned degree:

- ☐ Bachelors (1)
- ☐ Masters (2)
- ☐ Specialist (3)
- ☐ Doctorate (4)

Q14 Please indicate the area(s) in which you received the degree(s) marked above:

Q15 *Please complete the following question based on your current knowledge and perceptions. Please be as honest as possible. There are no right or wrong answers.*

Q16 Which of the following most closely describes your current knowledge and understanding of the new OAS-S?

- ◯ I don't know anything at all about the new standards (1)
- ◯ I know a little bit about the new standards (2)
- ◯ I have looked at the new standards and I am beginning to develop an understanding of how they work (3)
- ◯ I have looked carefully at the new standards and I have started to use them or think about using them in my classroom (4)
- ◯ I am familiar with the new standards and I am beginning to feel comfortable with using them (5)
- ◯ I am very familiar with the new standards and I use them almost exclusively in my classroom to select and design instructional activities. (6)

Q17 *Look at each aspect of the new OAS-S and indicate your comfort level with each one. Please be as honest as possible. There are no right or wrong answers. We just want to know where you are now.*

	Uninformed (1)	Novice (2)	Making Progress (3)	Getting There (4)	I've Got It! (5)	Expert (6)
Q17.1 Format & Structure of the Standards Document (1)	○	○	○	○	○	○
Q17.2 The 8 Science and Engineering Practices (SEPs) (2)	○	○	○	○	○	○
Q17.3 The 7 Crosscutting Concepts (CCCs) (4)	○	○	○	○	○	○
Q17.4 Disciplinary Core Ideas (DCIs) (7)	○	○	○	○	○	○
Q17.5 Performance Expectations (PEs) (5)	○	○	○	○	○	○
Q17.6 3-Dimensional Teaching (Integrating practices, crosscutting concepts, and core ideas) (6)	○	○	○	○	○	○

Q18 Indicate your current confidence level with implementing the new OAS-S by selecting a level from 1-10 on the following scale.

	Low				Medium				High		
	0	1	2	3	4	5	6	7	8	9	10
Confidence Level (1)											

Q19 Please explain briefly why you feel this way.

Q20 Based on your current understanding, describe the overall similarities and differences between the PASS standards for science and the new Oklahoma Academic Standards for Science (OAS-S). You do not need to consider specific standards. We are looking for broad similarities and differences.

Q21 *Please read each statement below and tell us the extent to which you agree or disagree with the statement by selecting the response that most closely resembles your current feeling. Please be as honest as possible. There are no right or wrong answers, just your perceptions.*

Q22

	Strongly Disagree (1)	Disagree (2)	Mildly Disagree (3)	Mildly Agree (4)	Agree (5)	Strongly Agree (6)
Q22.1 I enjoy teaching science. (1)	○	○	○	○	○	○
Q22.2 I prefer to teach science over any other subject. (10)	○	○	○	○	○	○
Q22.3 I think it is important to continually improve my science teaching. (4)	○	○	○	○	○	○
Q22.4 As a science teacher, I like to learn along with my students. (11)	○	○	○	○	○	○
Q22.5 Relevance is an important concern for me in my science teaching. (7)	○	○	○	○	○	○
Q22.6 I enjoy learning new ideas and concepts related to science. (8)	○	○	○	○	○	○
Q22.7 Students learn science best when they are able to discuss and collaborate to make sense of scientific phenomena that occur in nature. (9)	○	○	○	○	○	○

Q23

	Strongly Disagree (1)	Disagree (2)	Mildly Disagree (3)	Mildly Agree (4)	Agree (5)	Strongly Agree (6)
Q23.1 Science is a difficult subject to teach. (2)	○	○	○	○	○	○
Q23.2 Science is a difficult subject for students to learn. (1)	○	○	○	○	○	○
Q23.3 I think it is crucial for students at all grade levels to learn science. (10)	○	○	○	○	○	○
Q23.4 I think it is important to make connections between science and other content areas. (3)	○	○	○	○	○	○
Q23.5 Authentic applications of science concepts and principles are an important part of my teaching. (4)	○	○	○	○	○	○
Q23.6 I expect students to use what they learn in science class outside of school. (5)	○	○	○	○	○	○

Q24

	Strongly Disagree (1)	Disagree (2)	Mildly Disagree (3)	Mildly Agree (4)	Agree (5)	Strongly Agree (6)
Q24.1 I value creativity as part of the science process. (1)	○	○	○	○	○	○
Q24.2 Science instruction is an important aspect of student literacy. (2)	○	○	○	○	○	○
Q24.3 Science instruction is more important in secondary grades (6-12) than in elementary grades (K-5). (3)	○	○	○	○	○	○
Q24.4 I believe it is important for me, as a teacher, to interact with practicing scientists and/or engineers. (4)	○	○	○	○	○	○
Q24.5 I believe it is important for my students to interact with practicing scientists and/or engineers. (5)	○	○	○	○	○	○
Q24.6 I believe my educational background in science is adequate for me to be able to teach science effectively. (6)	○	○	○	○	○	○
Q24.7 I have a sound understanding of the science content I am required to teach. (7)	○	○	○	○	○	○

Q25

	Strongly Disagree (1)	Disagree (2)	Mildly Disagree (3)	Mildly Agree (4)	Agree (5)	Strongly Agree (6)
Q25.1 I am confident in my ability to create my own effective teaching activities for science. (5)	○	○	○	○	○	○
Q25.2 I am confident in my ability to learn new science concepts. (3)	○	○	○	○	○	○
Q25.3 I am confident in my ability to use inquiry methods in teaching science. (6)	○	○	○	○	○	○
Q25.4 I am comfortable leading a student science activity in which there is not a specifically defined answer. (2)	○	○	○	○	○	○
Q25.5 I like to give students choices in the content, process, and/or products of their science learning activities. (7)	○	○	○	○	○	○
Q25.6 I am confident in my ability to utilize 3-Dimensional instruction to integrate Science and Engineering Practices (SEP), Crosscutting Concepts (CCC), and Disciplinary Core Ideas (DCI). (8)	○	○	○	○	○	○

Q26

	Strongly Disagree (1)	Disagree (2)	Mildly Disagree (3)	Mildly Agree (4)	Agree (5)	Strongly Agree (6)
Q26.1 I am comfortable with using natural phenomena as the focus of my science instruction. (1)	○	○	○	○	○	○
Q26.2 I have trouble learning and understanding some concepts in science. (2)	○	○	○	○	○	○
Q26.3 I am confident in my ability to teach science. (3)	○	○	○	○	○	○
Q26.4 I am comfortable with managing a classroom in which students are actively participating in an investigation using science materials. (4)	○	○	○	○	○	○
Q26.5 I am confident that I can write my own lessons that address the new Oklahoma Academic Standards for Science (OAS-S). (5)	○	○	○	○	○	○
Q26.6 I have a good understanding of what Science and Engineering Practices (SEP) should look like for students in the grade level I teach. (6)	○	○	○	○	○	○
Q26.7 I have a good idea of what Crosscutting Concepts (CCC) should look like for students in the grade level I teach. (7)	○	○	○	○	○	○

Q27 *Please respond to the statements below by indicating how often you have your students do them in the classroom. There are no right or wrong answers.*

Q28

	Almost Never (1)	Rarely (2)	Occasionally (3)	Often (4)	Frequently (5)	Most of the Time (6)
Q28.1 I ask my students to make connections between science and other content areas. (1)	○	○	○	○	○	○
Q28.2 My science students work in groups. (2)	○	○	○	○	○	○
Q28.3 I ask my science students to analyze data they have collected. (3)	○	○	○	○	○	○
Q28.4 I ask my science students to use observations they have recorded as evidence for supported conclusions. (4)	○	○	○	○	○	○
Q28.5 My science students do investigations in which I provide the instructions, procedures, and guiding questions. (5)	○	○	○	○	○	○
Q28.6 My science students perform experiments which they have designed to test scientific questions posed by me (the teacher). (6)	○	○	○	○	○	○
Q28.7 My science students perform experiments which they have designed to test scientific questions that they have generated themselves. (7)	○	○	○	○	○	○

Q29

	Almost Never (1)	Rarely (2)	Occasionally (3)	Often (4)	Frequently (5)	Most of the Time (6)
Q29.1 I ask my science students to support their claims/explanations with evidence during discussions. (9)	○	○	○	○	○	○
Q29.2 I ask my science students to support their claims/explanations with evidence in writing. (8)	○	○	○	○	○	○
Q29.3 I ask my students to create scientific models. (1)	○	○	○	○	○	○
Q29.4 I ask my students to use scientific models to explain scientific concepts. (2)	○	○	○	○	○	○
Q29.5 I ask my science students to share their work with other students. (3)	○	○	○	○	○	○
Q29.5 I ask my science students to collaboratively share their ideas with other students. (17)	○	○	○	○	○	○
Q29.6 Students in my class use science notebooks (journals). (4)	○	○	○	○	○	○
Q29.7 I use natural phenomena as the focus or anchor of my science instruction. (5)	○	○	○	○	○	○
Q29.8 My students are given the opportunity to use the Engineering Design Process to plan and test solutions to everyday problems. (6)	○	○	○	○	○	○

Q30

	Almost Never (1)	Rarely (2)	Occasionally (3)	Often (4)	Frequently (5)	Most of the Time (6)
Q30.1 I ask my students think about science as occurring all around them in their everyday lives. (7)						
Q30.2 My science lessons utilize 3-Dimensional teaching that integrates Scientific and Engineering Practices (SEP), Crosscutting Concepts (CCC), and Core Disciplinary Ideas (DCI). (1)						
Q30.3 I provide definitions for applicable scientific vocabulary to my students prior to doing an investigation. (2)						
Q30.4 I use the textbook as the main student resource for science knowledge and principles. (3)						
Q30.5 My students read about applicable science concepts before they do a lab activity. (4)						
Q30.6 I expect my students to to use the textbook to become familiar with concepts before we do an activity. (5)						
Q30.7 I ask my students to engage in Science and Engineering Practices (SEP) to construct explanations for natural phenomena. (6)						

Q31 Are you Hispanic or Latino? (A person of Cuban, Mexican, Puerto Rican, South or Central American, or other Spanish culture or origin regardless of race.)

○ Yes (1)

○ No (2)

Q32 Please select the racial category or categories with which you most identify:

▢ Black or African American (1)

▢ Native Hawaiian or other Pacific Islander (2)

▢ Asian (3)

▢ American Indian or Native Alaskan (4)

▢ White (5)

End of Block: Default Question Block

Appendix E: CBAM Levels of Use Survey

Science and Engineering Practices (SEPs)

Please help us to understand your current use of the concepts of the OAS-S in your classroom.

CBAM Levels of Use of SEPs as included in the OAS-S in the Classroom Identifier: School:	
Please circle the number that best reflects your current level of use of SEPs in your classroom.	
Levels of Use	Behavioral Indices of Level
VI. Renewal	I am seeking more effective alternatives to the already established use of SEPs in my classroom (moving toward Three-Dimensional Learning).
V. Integration	I am making deliberate efforts to help others to use SEPs in their classrooms.
IV. Refinement	I am making changes in my use of SEPs in my classroom to increase outcomes.
III. Mechanical Use	I am using SEPs in my classroom, but they are not always coordinated with my course of study.
II. Preparation	I am preparing to use SEPs in my classroom.
I. Orientation	I am seeking more information on using SEPs in my classroom.
0. Nonuse	I am not taking any action in regard to using SEPs in my classroom

Disciplinary Core Ideas (DCIs)

Please help us to understand your current use of the concepts of CORPS in your classroom.

CBAM Levels of Use of DCIs as included in the OAS-S in the Classroom Identifier: School:
Please circle the number that best reflects your current level of use of DCIs data in your classroom.

Levels of Use	Behavioral Indices of Level
VI. Renewal	I am seeking more effective alternatives to the already established use of DCIs in my classroom (moving toward Three-Dimensional Learning).
V. Integration	I am making deliberate efforts to help others to use DCIs in their classrooms.
IV. Refinement	I am making changes in my use of DCIs in my classroom to increase outcomes.
III. Mechanical Use	I am using DCIs in my classroom, but it they are not always coordinated with my course of study.
II. Preparation	I am preparing to use DCIs in my classroom.
I. Orientation	I am seeking more information on using DCIs in my classroom.
0. Nonuse	I am not taking any action in regard to using DCIs in my classroom

Cross Cutting Concepts

Please help us to understand your current use of the concepts of CORPS in your classroom.

CBAM Levels of Use of CCCs as included in the OAS-S in the Classroom Identifier: School:
Please circle the number that best reflects your current level of use of CCCs in your classroom.

Levels of Use	Behavioral Indices of Level
VI. Renewal	I am seeking more effective alternatives to the already established use of CCCs in my classroom (moving toward Three-Dimensional Learning).
V. Integration	I am making deliberate efforts to help others to use CCCs in their classrooms.
IV. Refinement	I am making changes in my use of CCCs in my classroom to increase outcomes.
III. Mechanical Use	I am using CCCs in my classroom, but they are not always coordinated with my course of study.
II. Preparation	I am preparing to use CCCs in my classroom.
I. Orientation	I am seeking more information on using CCCs in my classroom.
0. Nonuse	I am not taking any action in regard to using CCCs in my classroom

Performance Expectations (PEs)

Please help us to understand your current use of the concepts of PEs as included in the OAS-S in your classroom.

CBAM Levels of Use of PEs in the Classroom

Identifier:

School:

Please circle the number that best reflects your current level of use of PEs in your classroom.

Levels of Use	Behavioral Indices of Level
VI. Renewal	I am seeking more effective alternatives to the already established use of PEs in my classroom (moving toward using in relation to Three-Dimensional Learning).
V. Integration	I am making deliberate efforts to help others to use PEs in their classrooms.
IV. Refinement	I am making changes in my use of PEs in my classroom to increase outcomes.
III. Mechanical Use	I am using PEs in my classroom, but they are not always coordinated with my course of study.
II. Preparation	I am preparing to use PEs in my classroom.
I. Orientation	I am seeking more information on using PEs in my classroom.
0. Nonuse	I am not taking any action in regard to using PEs in my classroom

Three-Dimensional Learning

Please help us to understand your current use of Three-Dimensional Learning (integration of SEPs, DCIs, and CCCs) as included in the OAS-S in your classroom.

CBAM Levels of Use of Three- Dimensional Learning in the Classroom

Identifier:

School:

Please circle the number that best reflects your current level of use of Three- Dimensional Learning in your classroom.

Levels of Use	Behavioral Indices of Level
VI. Renewal	I am seeking more effective alternatives to the already established use of Three- Dimensional Learning in my classroom.
V. Integration	I am making deliberate efforts to help others to use Three-Dimensional Learning in their classrooms.
IV. Refinement	I am making changes in my use of Three- Dimensional Learning in my classroom to increase outcomes.
III. Mechanical Use	I am using Three- Dimensional Learning in my classroom, but it is not always coordinated with my course of study.
II. Preparation	I am preparing to use Three- Dimensional Learning in my classroom.
I. Orientation	I am seeking more information on using Three- Dimensional Learning in my classroom.
0. Nonuse	I am not taking any action in regard to using Three- Dimensional Learning in my classroom

Appendix F: 3D Instructional Task Version 1

Three-Dimensional Instructional Task Narrative

(Remember that although they are separate sections below we want them to flow together to create a narrative.)

Author(s)	
Grade Level	
Instructional Task Title	

STEP 1: Determine what OAS-S content the lesson idea will target from the standards

List the targeted DCIs (from the Middle Green Column) below.
•

STEP 2: Identify possible phenomena related to the DCIs.

How do the targeted DCIs show up in nature/real life?

STEP 3: Decide which of the above phenomena you want to use to drive the instructional task.

What would you/students actually observe?

STEP 4: Construct an explanation* for why/how the phenomenon occurs using science ideas.

How can you incorporate the DCI in the phenomenon explanation?

*This is not where students construct the explanation. This section is so the teacher has an understanding of the underlying science concepts for the phenomenon in order to plan.

STEP 5: Decide how you will have the students collect data/information/evidence about the phenomenon.

How can you have students engage in Science and Engineering Practices to collect information they can use to explain the phenomenon for themselves?

STEP 5: Decide how you will have the students reason and make sense of the data/information/evidence.

How can you use Crosscutting Concepts to have students reason and make sense of the information in order to explain the phenomenon?

STEP 6: Decide how students will construct and share their initial explanations.

What strategies can you use to have students construct and share their initial explanations in a way that makes their thinking visible?

STEP 7: Decide how student understanding will be clarified and misconceptions will be addressed so that students' conceptual understanding is accurate.

What questions, strategies, further information, and/or investigations could you engage students with to construct accurate explanations?

STEP 8: Decide how students will revise their initial explanations based on their current corrected understanding.

What prompts and/or questions will you provide to students to guide them in revising their explanations? Will the students share their explanations again?

STEP 9: Decide what the next steps will be.

What are the next things students might do? (e.g. performance assessment task, formative assessment, move to related DCI phenomenon Instructional Task, etc.…)

Appendix G: 3D Instructional Task Version 2

PHENOMENON-BASED INSTRUCTIONAL TASK

Author(s)		**Grade Level (Content)**	
Title of Task			

Targeted DCI with Number of Associated PE
(Copy and paste from OASS)

Concise Description of the Driving Phenomenon
Brief scientific explanation in lay terms using targeted DCI(s)
What will students see, hear, or do?
Examples: pictures, data, video, demonstrations, direct observation…
(Include relevant pictures, links, or data sets)

How will students will initially process the phenomenon once it has been observed or experienced?
What might students do in order to begin thinking about an explanation for the phenomenon?
Examples: construct initial individual explanations before group processing has occurred, class discussion, pose group questions, manipulate elements of the phenomenon, look for data patterns…

What information or evidence will students gather to construct or refine an early explanation/model of the phenomenon?
What questions will be posed to students to guide collection of information or data?
(Highlight SEPs in which they will engage or CCCs they will utilize for reasoning)
(Include possible best answers to the questions)
(Include additional instructions that might be given to scaffold investigation)
What are the expectations for conceptual understanding of the phenomenon at this stage?
What will you look for in the early explanation/model to determine this understanding?
(What specific concepts should students correctly include at this point)

(This section is optional <u>or</u> may be used more than once depending on the complexity of the phenomenon.) **What (if any) further information or evidence will students gather to <u>refine</u> their early explanation/model of the phenomenon?** *What questions will be posed to students to guide collection of information or data?* *What are the expectations for conceptual understanding of the phenomenon at this stage?* *What will you look for in the early explanation/model to determine this understanding?*
What will you ask students to do that will show and/or communicate <u>individual</u> final learning? *What questions or instructions will be posed to get students to communicate their final understanding?* *What will you look for to determine their understanding related to the DCI and/or PE?* *(Specific concepts that students should correctly include in their final explanation/model)*

Appendix H: Sample 3D Instructional Task Version 3

PHENOMENON-BASED INSTRUCTIONAL TASK

Author(s)	K20 Center Staff	**Grade Level (Content)**	8th Grade
Title of Task	Wandering Water		

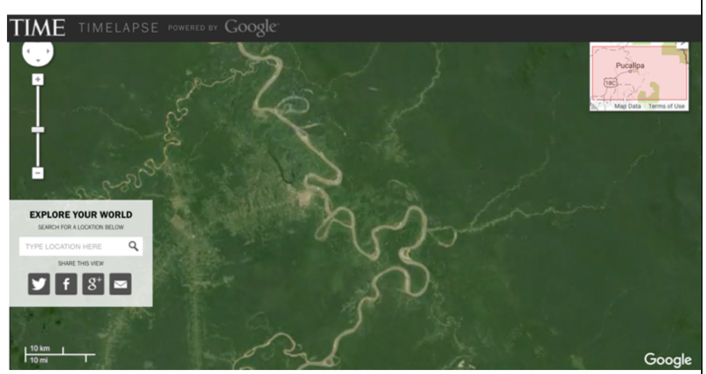
Targeted DCI and/or Associated PE

PE
OAS-S MS-ESS2-2
Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales.

DCI
The Roles of Water in Earth's Surface Processes
Water's movements—both on the land and underground—cause weathering and erosion, which change the land's surface features and create underground formations.

Driving Phenomenon

Student observation or initial interaction:
Students watch a time lapse video of the changes in the Ucayali River in Peru as it meanders over a 32-year period.



TIME TIMELAPSE Project powered by Google Earth Website - http://world.time.com/timelapse/
Ucayali River, Pucallpa, Peru time lapse (1984-2016)
http://world.time.com/timelapse2/

Lay Explanation/Description: Rivers can change course over time and assume a winding pathway with curves known as meanders. Sediment is eroded away from the outer curves of a meander where kinetic (motion) energy is high and is deposited at inner curves downstream where kinetic energy is lower. This movement of sediment can change the shape of a river and alter Earth's surface features on both a short-term and long-term scale.

How could students gather evidence that will help them construct/refine a supported explanation of the phenomenon using scientific and engineering practices (SEPs)?

1. Initial engagement with the phenomenon: Students ask questions after observing the time lapse video.
  o Possible engagement strategy – I Notice…I Wonder using a T-chart
 	
2. Students observe other locations from the http://world.time.com/timelapse2/ website to collect evidence from different places in the world where rivers and other water formations have shaped the earth over time. They look for patterns in the observation data they collect to help them determine cause and effect relationships.
  o Possible strategy for gathering and organizing data – Provide a graphic organizer for recording data (such as a Venn diagram) to document similarities and differences between water features at different locations in relation to changes to land surfaces
 	
3. Students use physical models to investigate effects of water moving over earth materials.
  o Possible strategy – students plan and/or carry out investigations of water movement on various earth materials, slopes, or water velocities/amounts using stream tables
  o Possible strategy – students view online simulations or videos of physical models (like stream tables) that show or allow students to investigate water movement on various earth materials, slopes, or water velocities/amounts (Example website: https://www.youtube.com/watch?v=5GVEPIKkor0)

What are some guiding questions that could be utilized to help students construct/refine a supported explanation of the phenomenon?

Overarching question: How does the movement of water change the surface of land?
 	
1. Initial engagement with the phenomenon
  ▪ What questions do you have about this phenomenon?
  ▪ Are any of these testable scientific questions?
  ▪ What types of evidence could we gather to help answer these questions?
 	
2. Observations of time lapse photos from other locations
  ▪ What similarities and differences do you notice between locations where water is changing the surface of the land?

- Are there any patterns you see that might help you determine a cause and effect relationship between water movement and changes in surface features?
- Is earth material eroded and deposited in similar ways in the different circumstances?
- In what ways is energy being transferred in the different water-land systems?

3. Investigations with physical models
   - How does the stream table model compare to a real stream or river?
   - How does this model help us understand interactions that occur on Earth's surface between land and water?

How might students communicate their understanding of the targeted DCI or PE in an explanation supported by evidence?

Students construct and then refine explanations for the phenomenon at various times during the task. This could involve an initial explanation after observing the time lapse, a revision of this explanation after observing and comparing different types of erosion processes on the time lapse website, and another revision after investigating effects of water in stream tables. These could be individual or group explanations. A final explanation could be generated in the form of a final revision or an alternate type of explanation. This final explanation should be done individually.

Possible formats for constructing explanations of this phenomenon.

- Students make a claim in the form of a Claim-Evidence-Reasoning (CER) statement. They provide an evidence-based explanation in this format. The claim could address a student-generated question or a teacher-provided question such as:
  - How does the course of a meandering river change?
  - How does water affect the course of a meandering river?
  - How do these changes effect Earth's surface features?

- Students draw and label a model that shows how water affects the course of a meandering river. These models can be used as visual aids in describing their ideas to others or can be part of a written explanation.

- Students create a physical model that demonstrates the effect of water. As they demonstrate the model to others, they point out evidence that shows how water affects the course of a stream.

How Does the Phenomenon Connect to the DCI or PE?
This phenomenon is one example of how "*water's movements—both on the land and underground—cause weathering and erosion, which change the land's surface features and create underground formations*." As students gather evidence to explain how a meandering river changes course over time, they are beginning to construct an argument to show how water interacts with earth materials in multiple ways to create a complex pattern of change to Earth's surface. This pattern includes processes involving not only water, but wind, sunlight, gravity and temperature interacting within the geosphere, atmosphere, and hydrosphere. As they broaden their experience with other phenomena like this one, they learn to use natural phenomena to provide evidence that "*geosciences have changed Earth's surface over varying time and spatial scales*." Using models may help provide them with a sense of scale that will facilitate their understanding of how to think about time scales that extend well beyond their own experience.

Appendix I: Sample 3D Instruction Task Final Version

CORPS
Central Oklahoma Rural Partnership For Science

PHENOMENON-BASED INSTRUCTIONAL TASK | **AUTHORS:** K20 Staff | **GRADE LEVEL:** 8th Grade

WANDERING WATER

TARGETED DCI AND/OR ASSOCIATED PE

PE | OAS-S MS-ESS2-2
Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales.

DCI | THE ROLES OF WATER IN EARTH'S SURFACE PROCESSES
Water's movements—both on the land and underground—cause weathering and erosion, which change the land's surface features and create underground formations.

POSSIBLE DRIVING PHENOMENON

Student observation or initial interaction:
Students watch a time lapse video of glaciers as they flow down a valley. (EXTREME ICE SURVEY - Funded by Earth Vision Institute - http://extremeicesurvey.org/)

Sample Student Explanation: *Glaciers form when layers of snow and ice accumalate. Over time the size and mass of the glacier increases. Gravity pulls the glacier down causing it to flow like a river. When the glaciers move they pick up and move debris and cause erosion to occur and reshape the surface of the Earth carving out valleys.*

Student observation or initial interaction:
Students watch a time lapse video of the changes in a RIVER as it meanders over a 32-year period. (TIME TIMELAPSE - Powered by Google Earth - http://world.time.com/timelapse2/)

Sample Student Explanation: *Rivers can change course over time. These pathways can vary from straight to curvy and wandering. This depends on how fast the water is moving. Because of gravity, water moves downhill. Rivers and streams that move slowly curve back and forth. Over time the moving water will pick up sediment from the banks and redeposit it in new places. This causes the river to change course and the Earth's surface is reshaped.*

K20CENTER THE UNIVERSITY OF OKLAHOMA
Noble
Funded by a USDE Math Science Partnership (MSP) grant through the Oklahoma State Department of Education.

HOW DOES THE PHENOMENON CONNECT TO THE DCI OR PE?

This phenomenon is one example of how "*water's movements—both on the land and underground—cause weathering and erosion, which change the land's surface features and create underground formations*." As students gather evidence to explain how a meandering river changes course over time or how glaciers shape Earth's surface by moving sediment, they are beginning to construct an argument to show how water interacts with earth materials in multiple ways to create a complex pattern of change to Earth's surface. This pattern includes processes involving not only water, but wind, sunlight, gravity and temperature interacting within the geosphere, atmosphere, and hydrosphere. As they broaden their experience with other phenomena like this one, they learn to use natural phenomena like these, they learn to use natural phenomena to provide evidence that "*geosciences have changed Earth's surface over varying time and spatial scales*." Using models may help provide them with a sense of scale that will facilitate their understanding of how to think about time scales that extend well beyond their own experience.

GATHERING AND REASONING IN ORDER TO CONSTRUCT AND REFINE EXPLANATIONS:

How could students gather evidence using SEPs and CCCs that will help them construct/refine a supported explanation of the phenomenon?

Students construct and then refine explanations (individual or group) for the phenomenon at various times during the task. This could involve an initial explanation after initial observation and ongoing revision of this explanation after continued exploration.

1. INITIAL ENGAGEMENT WITH THE PHENOMENON:

Students ask questions after observing the phenomenon. Overarching question: How does the movement of water change the surface of land?

- Possible question generating engagement strategy – I Notice…I Wonder using a T-chart
- What types of evidence could we gather to help answer these questio*ns?*

2. CONTINUING EXPLORATION:

Students observe other locations to collect evidence from different places in the world where rivers, glaciers, and other water formations have shaped the earth over time. They look for patterns in the observation data they collect to help them determine cause and effect relationships.

GUIDING QUESTIONS:

- What similarities and differences do you notice between locations where water is changing the surface of the land?
- Are there any patterns you see that might help you determine a cause and effect relationship between water movement and changes in surface features?
- Is earth material eroded and deposited in similar ways in the different circumstances?
- In what ways is energy being transferred in the different water-land systems?

Funded by a USDE Math Science Partnership (MSP) grant through the Oklahoma State Department of Education.

Students use physical models and or online simulations or videos to investigate effects of water moving over earth materials. E.g. students plan and/ or carry out investigations of water movement on various earth materials, slopes, or water velocities/ amounts using stream tables or glacier models.

GUIDING QUESTIONS:

- How does the model compare to a real stream, river, or glacier?
- How does this model help us understand interactions that occur on Earth's surface between land and water?

COMMUNICATE FINAL EXPLANATION OF THE PHENOMENON:

How might students communicate their understanding of the targeted DCI or PE in an explanation supported by evidence?

Students generate a final explanation in the form of a final revision or an alternate type of explanation. This final explanation should be done individually.

POSSIBLE FORMATS FOR CONSTRUCTING EXPLANATIONS OF THIS PHENOMENON.

- Students make a claim in the form of a Claim-Evidence-Reasoning (CER) statement. They provide an evidence-based explanation in this format. The claim could address a student-generated question or a teacher-provided question:
  - How does the movement of water affect Earth's surface?
  - What evidence can you provide to support this explanation?
- Students draw and label a model in the form of a diagram that shows how the movement of water can change the Earth's surface features. These models can be used as visual aids in describing their ideas to others or can be part of a written explanation.
- Students create a physical model that demonstrates the effects of water on Earth's surface. As they demonstrate the model to others, they point out the cause and effect mechanisms and and the related evidence that shows how water affects and alters Earth's surface.

Funded by a USDE Math Science Partnership (MSP) grant through the Oklahoma State Department of Education.

Appendix J: Instruction Task Lesson Study Debrief Protocol

Partners: ____ & ____

Partner 1 Partner 2

Grade Level: ______________

Name of Instructional Task: ____

ROUND 1 – Teaching Instructional Task Draft

Taught by: ____________________________ on ________________________

Partner teaching task Date

Debriefed by: ____ on ____________________

Partner observing & K20 Team members Date

Reflection Questions:

1. In what ways did the design of the task encourage students to generate ideas, questions, evidence, or conclusions?
2. What elements of the task best promoted student engagement?
3. Is the phenomenon appropriate for addressing the grade level disciplinary core idea? Why or why not?
4. What scientific and engineering practices seemed to contribute to the students' ability to construct explanations for the phenomenon and/or DCIs?
5. Were students successful in using evidence to construct well-reasoned and accurate explanations? Why or why not?
6. In what ways did students use crosscutting concepts in constructing their explanations?
7. Were all three dimensions successfully integrated into the task as expected? How did this occur?
8. In what ways did the phenomenon drive the instruction?
9. What is needed to modify or improve this task?
10. What have you learned from using this instructional task that will help you in teaching future concepts?

ROUND 2 – Teaching Revised Task

Taught by: ______________________________ on __________________________
Partner teaching task Date

Debriefed by: ____ on ______________________
Both Partners Date

Reflection Questions:

1. In what ways did the design of the task encourage students to generate ideas, questions, evidence, or conclusions?
2. What elements of the task best promoted student engagement?
3. Is the phenomenon appropriate for addressing the grade level disciplinary core idea? Why or why not?
4. What scientific and engineering practices seemed to contribute to the students' ability to construct explanations for the phenomenon and/or DCIs?
5. Were students successful in using evidence to construct well-reasoned and accurate explanations? Why or why not?
6. In what ways did students use crosscutting concepts in constructing their explanations?
7. Were all three dimensions successfully integrated into the task as expected? How did this occur?
8. In what ways did the phenomenon drive the instruction?
9. What is needed to modify or improve this task?
10. What have you learned from using this instructional task that will help you in teaching future concepts?

Appendix K: Semi-Structured Interview Protocol

Semi-Structured Interview Protocol

1. How would you describe your involvement with CORPS?

2. How has your involvement with CORPS influenced your views toward the implementation of OAS-S in classrooms in this state?

3. Has your involvement with CORPS made you feel more confident in your own ability to positively impact the implementation of OAS-S in classrooms in this state?

    a. If Yes, then please elaborate.

4. In what ways has your interaction with the OAS-S and 3-Dimensional teaching practices through the CORPS PD influenced your teaching practice?

5. In what ways has your interaction with the OAS-S and 3-Dimensional teaching practices through the CORPS PD influenced your attitudes and feelings about the way science instruction should be approached?

6. Please talk about your experiences with implementing the new science standards into your teaching practice. In what way(s), if any, has your experience with CORPS influenced that process for you?

7. Please talk about your experiences with using scientific phenomena and engineering problems with your students. How have your students responded to this and how has it affected the instruction in your class?

8. What experiences from your participation in CORPS have most strongly impacted your understanding of 3D learning and teaching?

9. What experiences from your participation in CORPS have most strongly impacted your ability to implement 3D learning and teaching?

Appendix L: Exemplar Teacher Artifact 3D Instructional Task

Three Dimensional Instructional Task Narrative

(Remember that although they are separate sections below we want them to flow together to create a narrative.)

Author(s)	Jill
Grade Level	9-10
Instructional Task Title	Why are the plants so bent out of shape?

STEP 1: Determine what OAS-S content the lesson idea will target from the standards

List the targeted DCIs (from the Middle Green Column) below.

LS1: From molecules to organisms: structures and processes

- LS1-5: Organization for Matter and Energy Flow in Organisms:
  - The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen.
- LS1-4: Growth and Development of Organisms:

- Cellular division and differentiation produce and maintains complex organism, composed of systems of tissues and organs that work together to meet the needs of the whole organism.
- LS1-1:Structure and function
  - Systems of specialized cells within organisms help them perform the essential functions of life.
- LS1-3: Structure and function
  - Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range.

STEP 2: Identify possible phenomena related to the DCIs.

How do the targeted DCIs show up in nature/real life?
Potted plant is tipped yet the plant's leaves are growing upright toward the light source. Hanging tomato plants Chicago Cubs Wrigley field - wall behind outfield is covered by vines Solar tracking by sunflowers

STEP 3: Decide which of the above phenomena you want to use to drive the instructional task.

What would you/students actually observe?

Phototropism

I showed the pictures above to the students and asked for explanations.

STEP 4: Construct an explanation* for why/how the phenomenon occurs using science ideas.

How can you incorporate the DCI in the phenomenon explanation?

- Plants use a variety of hormones to control their growth and development. Specific hormones called auxins are produced in the meristems of plants that promote or inhibit growth.
- Auxins are responsible for promoting cell elongation that is required before a cell differentiates. As it increases water intake, the elasticity of the cell is also increased.
- Auxins are found in the shoot tip, which is responsible for directional movement by the plant in response to sunlight. Sunlight will actually eliminate the hormone which will cause the shaded portion to undergo more cell division and elongation. This results in a bent appearance of the plant as it leans towards the sunlight.

*This is *not* where students construct the explanation. This section is so the teacher has an understanding of the underlying science concepts for the phenomenon in order to plan.

STEP 5: Decide how you will have the students collect data/information/evidence about the phenomenon.

How can you have students engage in Science and Engineering Practices to collect information they can use to explain the phenomenon for themselves?
• Students will research and evaluate the scientific explanation for plants growing/ bending toward the light source. • Explanations will be constructed as they design an experiment to test one of their predictions (from the observations of the phenomenon.) • Evaluate other students' models while communicating with others during the gallery walk.

STEP 6: Decide how you will have the students reason and make sense of the data/information/evidence.

How can you use Crosscutting Concepts to have students reason and make sense of the information in order to explain the phenomenon?
Cause and effect: Mechanism and explanation Structure & Function Stability and change

STEP 7: Decide how students will construct and share their initial explanations.

What strategies can you use to have students construct and share their initial explanations in a way that makes their thinking visible?

Research and Write

- Construct an explanation for the direction of growth toward the light source.

Group Presentations

- Draw a model of a plant exhibiting other tropisms, labeling the positive and negative reactions toward the desired stimulus.

Gallery Walk

STEP 8: Decide how student understanding will be clarified and misconceptions will be addressed so that students' conceptual understanding is accurate.

What questions, strategies, further information, and/or investigations could you engage students with to construct accurate explanations?

- "Are plants able to exhibit phototropism and geotropism simultaneously?"

STEP 9: Decide how students will revise their initial explanations based on their current corrected understanding.

What prompts and/or questions will you provide to students to guide them in revising their explanations? Will the students share their explanations again?

Students will be able to modify their models to include additional behaviors exhibiting tropism.

STEP 10: Decide what the next steps will be.

What are the next things students might do?
(e.g. performance assessment task, formative assessment, move to related DCI phenomenon Instructional Task, etc…)

- Formal Assessment Probe: "Cucumber Seeds" Uncovering Student Ideas in Life Science by Page Keeley.
- Home Experiment: Limit the amount of direct sunlight of a current plant that is not currently exhibiting phototropism. Take a picture of the plant from a specific spot same time every day for two weeks and compare the daily / weekly photos to observe the changes in tropism. Rotate the plant to test if the plant will continue this behavior once again.
-

Appendix M: Exemplar Theme Chart

Jane Theme Chart

SURVEY INFORMATION	Representative Quotes
Grade Taught	6th Grade
Teaching Experience	12
Setting	Rural Middle School
Highest Degree	Bachelor
	Representative Quotes
EVIDENCE OF GROWTH/GROWTH OUTCOMES	
Started Project Overwhelmed/Frustrated/Bored	Well the first day was like any first day. I was overwhelmed. There was all this new stuff. And what have I signed up for? This in three years, what is this going to be? But we were able to backtrack and kind of baby step into it and it was an eye-opening experience because I thought, I thought I went to a workshop and knew how to teach these new standards. And that first day I realized that I didn't know anything. But now, now I feel like I could teach a workshop. So, not that I want to but at least I feel like I could. (361)
Being a Facilitator vs. Teacher	The students really respond to it because it's more student led. And they like, they like sharing their ideas and they're more engaged when they can tell you how it is and then let that pass or fail. As for me just sitting there and teaching them how to. (224) They do share more, and I teach less this this way. I plan more but teach less. I'm talking less and that's been totally weird. You just coming in as a teacher. Every year you have your whole I have my whole spiel on cells and I have my whole spiel on body

	systems. I know I can give them a whole lesson I can write notes verbatim I don't have to look at it and I know this stuff. But now I'm not really supposed to do that. I can do that if I want, but first we have to discover it and first I have to engage them. And so, it is a shift of coming up with cool stuff to try to make it more discovery. Which we've been trying to do for years. But there was a big stress on inquiry. And so, you want to make it more inquiry, but at the same time, we were never taught that way. We were taught, these are the notes and so it is probably easier for some of the newer teachers. But it's harder for us to totally change how we teach the way we were taught. (253) Because they're all engaged and they're all working and trying to come up with their experiment. So, you just have to walk around and be the facilitator. So, you know, it's a different kind of teaching you're not you know fussing at kids for not working. You're not teaching them long lectures. You're walking around and making sure that they're trying to answer the question you've given them. (289)
Students Develop Concept for Themselves	I tried to make it more visual and self-discovery as much as I could make succession, self-discovery and then and then I had. And then I went back. (68) We did an engineering and came up with the way we talked about gravity and how to combat gravity and come up with an egg drop, something around our egg to keep it. And it's something I did every year before

	now too. But this year I made sure that I taught more and let them lead. And give them more examples and kind of how to do it. And then let them research and submit pictures and test. (300)
Students Experience Concept	I'm teaching more science and less notes. (346)
Previous Style of Teaching vs. Now	In trying to teach the three the instructional task and that sorry the three-dimensional I've done more labs. And the labs have had more of an engineering aspect. Whereas before I never even had that. (156) Before I came to this three-year journey, is, I never would just give my students a bunch of supplies and tell them to design their investigation and I'm doing that a lot. Where I'm having them design their own investigation. Which is good because they have to know the scientific method in order to design their investigation. They have to know, they have to be engaged, they have to be knowing what we're doing in order to do that. So, yes that's been crazy as far as me saying here's some magnets go investigate as a from a classroom management perspective. But it works and in some ways it's an easier classroom management day. (278) Before my principal told me engage all learners and so I would read a book one day or I would do a lesson and I have them take notes and then I would watch a video on it. And I would teach like I was taught, and I would tell them what to do and then we would do a lab on it. OK. And so, and I tried to get away from that sometimes, because you're supposed to teach inquiry. But I didn't I didn't

	do it a lot. And this time, with these three years, I know how to put, how to find phenomenon, how to find pictures to put it in as bell work, and how to put in and to find probes to be able to write probes like Page Keely and have lots of choices and start sticking them in so that you were getting students to think, constantly. And you're constantly making sure that they are engaged. And I truly have use the book as a crutch. And so, it's only this year that my students can tell you we use the book when [teacher] was gone and there was a sub. And before we were in that book every chapter. We were reading a little bit about it. And this time I'm using phenomena and different investigations and activities. We were able to totally stay away from that. And I was able to use, OK as you're doing this activity go to this book and this page for help if you need to. And it was totally a resource and they could use their phones for resource. So, there was a lot less lecturing and a lot less reading and more science. (312)
Students Exceed Teacher Expectations	I didn't expect it and I didn't expect to spend 5 10 minutes on a phenomenon. I didn't expect them to get that excited about it. And in doing this more I have learned to plan more that way. (119) None of my plans of ever gone exactly like I pictured it which is kind of what makes teaching fun because you have students that sometimes excel your expectations and sometimes the just fighting against it. So, it’s never boring. So, I expected it to go a little smoother than it did on my classes that day. And they still

		were excited and knew succession by the end of the day. (121)
3D Teaching in Practice	Examples	I think it was just one tree growing in the middle like a Mexican city that there was nothing else and everything was desert and there was just one tree there. And so, the questions were kind of like how to get there? What caused this? What? It was like growing through the pavement. So how does it grow through the pavement? And so, so they generated a bunch of questions to. I was excited about that. (88) I have totally changed my teaching so that I model them to death because of CORPS and whatever task it is there is a model. And then this next task there is a model. And the next task there's a model. And so being able to draw and come up with models helps empower students and it helps them to feel more confident. (238) This year in order to incorporate engineering the first time I did it is we did this Penguin thing. And we had to design a home for their Penguin and that was phenomenal to watch the engineering practices and their thoughts and ideas. I talked about more models. I talked about more labs and pair working and solving problems.(250) They're more interested. When I did magnets, I used the phenomenon of the maglev train and then pass the magnets around let them see how it could levitate and push each other and then I have them do an idea that I got from CORPS and work with the magnets.(275)

		The phenomenon was used to get kids asking questions. The phenomena - evidence of engagement is the great questions students were asking about the picture of the plant in the middle of the concrete and the explanations they were putting forth and rebutting The card sort got great conversation and discussion from the students Succession play - found themselves in the videos they saw later, indicating they were engaged and got something from the activity The scenario about what would happen if your school was vacated was also engaging. Drawing the pictures helped focus them a bit as well. Yes - students were interested and engaged into the task right away (Q1-3)
3D Teaching in Practice (contd)	**Relevance to Students**	It's important that students know that things naturally come back and it's important to know what, and for them to know that there is some benefit at them being destroyed. That it's not all bad. That some people, you know, will make succession happen. And in order for farming tasks and stuff. It applies to ecology. (25) In this case I try to tie in the fields that we see, and I try to tie in farming and, and we go ahead, and we talk about like east and west coast how they might be more trees. And their climates community takes longer. But I show them pictures of like the 1999 tornado and I showed them, of their area where they, [local town] where they know. And I try to show them and pictures of succession and of things coming back. So, I do try to make it relevant. It is their town, their

3D Teaching in Practice (contd)		area. And I try to show pictures of farmers doing this on purpose. We don't have forests so, and this comes natural to just tailor it to them. (51)
	Integration (cross curricular/interdisciplinary related to daily pressure and requirements)	
3D Teaching in Practice (contd)	**Perceptions**	I thought they could walk away knowing it and physically being there and being able to visualize it and draw a model at the end because they knew it so well. (16) In some ways I was doing some of the crosscutting concepts and patterns anyway. And now I'm making sure that I'm doing them and. But what's really changed is, and in some ways this aspect is the way we're teaching now in some ways is better because there's less paperwork, and if you do this right, if you do this right in some ways there's more planning and less things to grade. But it is something that I've had this totally switch how I built my classroom around. I had to make sure that I taught procedures in place so that it was a safe environment for them to hear and listen to students and for us you have to. You have to be able to prepare for the kids to fail and fail and be comfortable to fail. (134) I do feel like we should have a shift of where if we're going to be tested where there's more reading and analyzing that we should be doing more formative assessments with more reading and analyzing and give students a chance to practice doing models. (235) I feel like nationally we should all be more on the same page because we're

		all forcing students to try to think for themselves, be able to solve more problems, and be able to have that, to be able to make a claim, and say their evidence, and support their views. And that's what the new science standards are all about. (241) Big takeaways, phenomenon first, model-model-model, and have students draw their model, have students investigate, have students model how they're going to investigate, and then have since fixed their model Assess along the way. (371)
GROWTH SUPPORT STRUCTURES/STRUCTURES TO SUPPORT LEARNING		
Internal Processes	Opportunities for Self-Reflection/Realization	The CORPS project did change how I was teaching completely. Because honestly when my principal told me to sign up for this I thought I knew everything. I thought I knew what the standards where. I thought I knew how to implement them and how to teach them. And then I came in and I realize that I didn't even scratch the surface of what they were asking me to do. I thought I looked through and thumbed through and looked at my book and thought okay well I'll just teach this and not this. And I really was totally missing the mark and I didn't know what crosscutting concepts were. I didn't know I had to do engineering practices. I didn't know how to do it. I didn't know how to ask questions. I didn't know how to assess them. They came in and said Oh you need to do this. You know you need to get the higher levels of Bloom's taxonomy. And then you got to be asking your students more questions and I didn't know how to

		ask these questions. I didn't know how to get that higher-level thinking. And then the last three years I've been able to feel comfortable and writing tasks and even writing assessments and feel like I am teaching what I'm supposed to be teaching. (164)
Internal Processes (contd)	Opportunities to Understand 3D Standards (e.g. how to read, dimensions, integration)	The phenomenon relates to the DCI about physical or biological components affecting populations - could also work with changes in ecosystems. (Q3)
Internal Processes (contd)	Opportunities for the Teacher to be the Learner	It has because it did make it easier and seeing. Coming to CORPS wasn't just, this is the standard. That every time they had an example of how to teach it, how to make science fun, a lesson that we could actually do in our class. (207) The things I like the most and the things I've been most helpful have been the summer where everyone, they would do lab after lab and we would, we would do this instructional activity with we explore this phenomenon and then we'd investigate it and then we talked about and then we go back and redo our model. And seeing that modeled over and over again, on here's your phenomenon. Now here you go with it. Now what how has your thinking changed? That is what's totally changed my thinking. Because that's what I'm now teaching constantly. OK. When we done? OK. Now how did that change your thinking? And before I never ever did that. (331) The other thing that was really great was when the Phillip Bell came in and showed us how to look at assessments and how to make assessments of how

		to analyze assessments. And that's totally rocked my world and change how I was thinking and that work, that made my year easier because my principal basically asked me to do the same thing. And so now I can write assessments and see what I was asked to do so much easier. And so, they were helpful, and they made me understand what I was really supposed to be teaching. And then they modeled it over and over again for me. And then they taught me how to assess it. And then they taught me how to analyze that. So, they taught me how to grade those assessments and so everything about CORPS has been making my life easier and making me a better science teacher because I'm teaching more science and less notes. (338)
Internal Processes (contd)	Opportunities for Encouragement and Belief in Self	I think what CORPS has taught teachers, that any teacher can do this. That it is easy to implement. (200) They helped build my confidence. And then I felt like I was doing what I was supposed to be doing. (378)
External Structures	3D Instructional/Assessment Task Model Structure	CORPS also gave me a bunch of resources. So not only did they change my model on how I am and basically gave me a whole model so now I have a new model how to plan every time. Now I have resources to go to find things and I know what I need. They showed me how to do it and then they made it easy for me to do it. (352) They changed my whole lesson plan outlook. And so, they gave me exactly how to do a new lesson plan. They gave me how to do assessments and so they re-taught me how to teach, and plan for teaching, and then they

External Structures (contd)		gave me the stuff to do it and doing so they helped build my confidence. And then I felt like I was doing what I was supposed to be doing. (376) Sequencing activities is part of the art of teaching - you have to experiment to see what works best. In general, it is better to do vocabulary first and vocabulary last. (Q10)
	Instructional/Assessment Tasks Database	
	Resources and Strategies	one thing it did is it made, it gave me more stuff to do, more options and they even gave us a cool book. And so, I have more teaching tools because of CORPS. And then I've been given example after example how to do it. (209)
	Phenomena Database	
	Peer Collaboration	My friends and I are working hard, and I have a co-worker that got to do CORPS the last two years too. And her and I are trying to get our third team member to not rely on the book as much. And to try to teach her how to ask the harder questions and to put in. So, we've given her the links and we've tried to show her and give examples as much as we could to try to do this for her. (196)
	Project Staff	
DRIVING MOTIVATION		
Restored Joy/Hope/Fun to Teaching		It was entertaining and chaotic. And they remembered it. (38)
Seeing Students Succeed		They had a phenomenon. We talked about the phenomenon. And I was really surprised and excited. But showing the picture of the phenomenon, because this is my first

	time really trying to implement this. And I showed the picture of the phenomena and the amount of them telling me, getting excited about the possible explanations for the phenomenon. And just really talking. It was more student led than I have ever let it be. And it was one of the best days ever because they got so excited about why the phenomenon occurred and so we did. (76) The questions were kind of like how to get there? What caused this? What? It was like growing through the pavement. So how does it grow through the pavement? And so, so they generated a bunch of questions to. I was excited about that. (90) Teaching this way has resulted in more science conversation from students because you are engaging them more and the conversation you get is amazing. Doing the succession play was fun but a bit chaotic. When you teach the concept of succession before the play (like Julie has done it before) there is less silliness but maybe not as much learning. The tradeoff for doing the activity first and the concept last can be a little bit of chaos. Teachers just need to decide when it is worth it and when it isn't. (Q10)
Helps Me be the Teacher I Want to be	I've always tried to steer away from worksheets as much as I can and try to do a little bit of everything. And try to make things as hands-on as possible and not do book work all the time. And this year I've actually accomplished that. Where my book is a resource and it's not, and none of my students feel like they ever do

	anything in the book. I don't know. I work sheeted them to death. (181) The last three years I've done lots of things to try to become a better teacher. And I have I gone to different workshops and ones that have implementing music in the classroom and brain breaks and teach like a pirate. And then I go to CORPS. And so, I've been trying to mesh all of them together and it has been a phenomenal difference and I have enjoyed teaching and gotten so much more confidence because I had so much better results. (218)
3D Model Makes Teaching Easier	A simple kind of assessment was how well they listened because they could show me in order the cards. So that was a way. And I liked that because it wasn't, it was quick, it was fast it wasn't writing. They like it too. (111) Since I've been at this I've been doing more. Before I didn't even know what, a formative assessment was. And so, I've been doing assessments along the way which is helping me teach better and make sure that they know it more. (145) Before I came to this three-year journey, is, I never would just give my students a bunch of supplies and tell them to design their investigation and I'm doing that a lot. Where I'm having them design their own investigation. Which is good because they have to know the scientific method in order to design their investigation. They have to know, they have to be engaged, they have to be knowing what we're doing in order to do that. So, yes that's been crazy as far as me saying here's some magnets go investigate as a from a classroom

	management perspective. **But it works and in some ways it's an easier classroom management day.** (278) Everything about CORPS has been making my life easier and making me a better science teacher because I'm teaching more science and less notes. (345)
Spread the Word	My friends and I are working hard, and I have a co-worker that got to do CORPS the last two years too. And her and I are trying to get our third team member to not rely on the book as much. And to try to teach her how to ask the harder questions and to put in. So, we've given her the links and we've tried to show her and give examples as much as we could to try to do this for her. (196)

Appendix N: Exemplar 3D CoRe

Kara 3D CoRe

	A: Main Concept	B: Secondary or related concept
Big Science Ideas/Concepts – (What is/are the targeted DCI(s)?	**Natural Selection:** • Sometimes the differences in characteristics between individuals of the same species provide advantages in surviving, finding mates, and reproducing.	We also make sure uncovered adaptations and habitat and how that played into the survival of the different animals.
1. What do you intend the students to learn about this idea/concept? (What is/are the targeted PE(s)?)	3-LS4-2 Use evidence to construct an explanation for how the variations in characteristics among individuals of the same species may provide advantages in surviving and reproducing.	I want to be able to identify the different things, the characteristics that each bear had and to be able to tell me why it was important to their survival. And I wanted them to observe the bears and their environments and then tell me their reasoning behind it be able to write it and communicate that back to me. And at that point I needed them to write and be able to write their explanations. And I needed them to be able to convey those explanations clearly.
2. Why it is important for students to know this?	Part of this lesson and part of the skill was going in and tying it back with our reading lessons that we've been doing. So, we tied up with all the ELA skills that we had and then took this lesson as an extension to give them some nonfiction readings and nonfiction information and have them relate it back to fiction items.	
3. What else you might know about this idea (that	I knew that they could not live in the different	

you don't want the students to know yet)	environments unless they were in a zoo type situation. And I knew that they required different kinds of foods and they could live in different kinds of environments based on their, what their body was made of and how their body structure is. And I knew that they had several similarities and a lot of differences and I wanted the kids to be able to find the similarities and differences when they were comparing and contrasting them.	
4. Difficulties/limitations connected with teaching this idea	Well some of the difficulty we have here is not a working smart board. Another difficulty we had was limited technology but that's changed now. I mean it was limited then and now it's better and it was worrying whether or not I could keep the kids interest in what we were talking about. And if they would be interested and they would want to learn more and see more. I was afraid that they get bored with just looking at still pictures or looking at short video, so it was me stepping out of a comfort zone going into technology and finding lots of videos that kids can see and watch the bears actually moving and doing different things. Comfort Zone was not technology at all, is not.	
5. Knowledge about students' thinking that influences your teaching of this idea	I knew that this age level they were there really interested in all kinds of animals and pets. I also knew that this age level. They loved to read about how one animal might attract to another animal and might be different and what would happen if they met in the wild. So I took that and	

	expanded with different animals and we had talked about penguins and we had talked about other things beforehand so they had an interest. And I also knew that in our community bears was something they don't they don't see. They see them in a zoo. They're not naturally occurring here. We have coyotes. We have bobcats. But we don't have bears. And I knew that would be something new for them to learn, so I thought we could make it exciting.	
6. Other factors that influence your teaching of this idea	How I could tie it in with everything else that we do in the day. Because we are told, and I know it sounds bad, as a school to focus on reading or ELA and math because that's what we're tested on. So, I had to make sure I could focus it in and use it with the ELA skills and the math. And I could get the science in that way and I could get whatever else we were talking about in.	
7. Teaching procedures (and particular reasons for using these to engage with this idea) (How will student engage in the SEPs and utilize the CCCs to investigate and explain Phenomena related to the DCI?)	So, there's the science and engineering practices. And as we observe the characteristics we observed color size habitat of observations engineering. I know I took and had them do the blubber glove, so they could feel the difference on that. We did a lot of things beforehand. And I know I changed some too. Engaging the children. Making sure that all students were engaged during the time we were discussing and looking at things. Being certain that it was the things they notice, things we could put down their notebooks, and they could take notes on. And I had to think how I was going to use it next what	

	I was going to do with it next. So, I did lots of research on my own and then after we did the whole lesson I had the kids go back and research the two bears with the iPad because we had the time, and had them do some research on the two and then make up charts to describe the two and teach another class about them. I kind of made sure that those two worked well together. We did lots of cause and effect. We did lots of patterns. We did scale because we talked about the size and the way in which one was bigger which was a smaller and compared it to things that they knew around us and about the same size. We talked about the energy cycle and how they get their food. What happens if they're not there. And then we also did the stability and change a lot because we talked about what happened if and I had them write down some ideas of what would happen if the bear was in of places what would happen if and then I had to go back and research the climate and the two areas. And with that climate and the facts they knew about each bear, which one would better survive in a made-up climate that I gave him the.	
8. Specific ways you will use to ascertain students' understanding or confusion around the idea (How will you utilize Formative and/or Summative Assessments to evaluate if the student has met the targeted PE(s)?)	I did lots of small checks as we went along and the small checks that I thought about, I changed as I taught it. But I thought about you know watching as they wrote in their notebooks, having them write, do a Venn diagram comparing the two, having them use any prior knowledge that they might have and discuss what they	

	knew already. And so, was that they could go in and do a little short assessments of do they know that the polar bear is in the Arctic? Do they know that the brown bear is in a forest? And so, when we did the I call it a brain dump. When I had the kids do a brain dump and write down everything that they knew it gave me a good idea of what they knew, and they didn't know. And then when I did the second brain dump at the end it gave me an idea if they had gotten anything and let me know that they had a better understanding just by the terms that they were using. Because they started out they were using terms like brown, white, big, small. We finished up they were using it is greater, it's mass is, it's fur is more dense or it's far more translucent. They were used in the more scientific terms. So I kind of just looked at to see, I had a list written down on my desk, I kind of look to see if they could use those terms effectively in their writing. I look to see if when they were taking their notes in their notebook that they could, that those things were labeled correctly in their notebooks. I looked to see if when they were doing their presentations and their research if they use those terms and if they use them correctly.	

Appendix O: Exemplar 3D Instructional Task Reflection Sheet

INSTRUCTIONAL TASK REFLECTION SHEET

Partners: **Irene &**
Partner 1 Partner 2
Grade Level: **4th**
Name of Instructional Task: **Weather Away**

ROUND 1 – Teaching Instructional Task Draft

Taught by: **Irene on Dec. 8,2016**
Partner teaching task Date

Debriefed by: **Partner and Project Team Member Dec. 8, 2016**
Partner observing & K20 Team members Date

Reflection Questions:

1. In what ways did the design of the task encourage students to generate ideas, questions, evidence, or conclusions?

   In this task the phenomenon was placed after the investigation. The students were given the opportunity to create their own knowledge and it generated a lot of conversation and questions.
   Showing the video first would have totally given it away and taken away their curiosity thus curtailing the students opportunity to use their higher order thinking skills.
   This allowed the students to really focus in on what they were observing. Students used scientific vocabulary as they conversed with their team. Vocab examples: contracting, expanding, melting, dissolving, absorbing, liquid, particles

2. What elements of the task best promoted student engagement?

   - **The design of the sequence of the investigation.**
   - **The fact that it was hands-on.**
   - **The hands on exploration with the graham crackers and the sugar**

cubes that simulated a sinkhole.

- **The video of trees being pulled into a sinkhole, because they could not tell that the trees were being pulled into a sinkhole this left them with more to think about.**
- **Other videos of more sinkholes that were very obvious**

3. Is the phenomenon appropriate for addressing the grade level disciplinary core idea? Why or why not?
   - **Yes, because dissolving matter and erosion of the layers beneath the crust creates sinkholes.**

4. What scientific and engineering practices seemed to contribute to the students' ability to construct explanations for the phenomenon and/or DCIs?

   #1- Asking questions
   #2- Developing and using models- the students created a model of a sinkhole. This was part of the exploration and was not identified as a sinkhole until later in the discussion. This could possibly be labeled on their drawings in a follow-up lesson.
   #4 -Analyze and interpreting data- Students analyzed what was happening in their experiment after each session of dropping the water droplets.
   #6- Constructing Explanations- Students started to construct explanations. This may need to be elaborated on in the next lesson. Students revised their thinking as the lesson progressed.
   #8- Obtain, evaluating, and communicating information- Students were evaluating and revising their thinking as more information was gained.

5. Were students successful in using evidence to construct well-reasoned and accurate explanations? Why or why not?
   - **Students discussed their ideas for how a sinkhole is made with their team and then shared with the whole class.**
   - **Possibly using a CER to help them construct their knowledge. This helps them get their thoughts in writing and be accountable for their claim and reasoning.**

6. In what ways did students use crosscutting concepts in constructing their explanations?

   Cause and effect –The more drops of water the deeper the hole.

7. Were all three dimensions successfully integrated into the task as expected? How did this occur?
   See answers for questions # 4 and #6

8. In what ways did the phenomenon drive the instruction?
   The investigation drove the lesson until the phenomenon video was shown. Students then were asked to compare and infer how the investigation related to the photos and clips of sinkholes.
   The phenomenon was used to engage the students to ask more questions and led the students to ask, "Can we lift up the graham cracker and see what is underneath?"

9. What is needed to modify or improve this task?

   - **Have the students lift up the graham cracker before showing (the phenomenon) of the sinkhole photos. Students can then name what they see.**
   - **Possibly during a later lesson, compare the graham cracker and the water drops to nonporous surfaces.**
   - **Clarify the difference between quicksand and a sinkhole**
   - **Compare the sugar cube to something that is not porous to show that some objects will not soak up water, dissolve, water can't run through or around it. (May actually use sand or granite and keep the graham crackers as the earth's crust)**
   - **Use only water the first time and the vinegar could be used as a possible relationship to acid rain. We discussed that this lesson didn't focus on acid rain. Possible do one with water and one with vinegar and look at the difference.**
   - **Use a (CER) Claims, Evidence, Reasoning as an opportunity for the students to explain their reasoning and evidence.**

10. What have you learned from using this instructional task that will help you in teaching future concepts?

I loved the students' reactions and I thought it was fun to teach this way. The students can feel the enthusiasm of the teacher and were totally engaged. I usually don't have a full class but I am thinking about how this would work for my SPED classes.

I think the format of the lesson plan helps us to plan a well thought out flow to the lesson.

Teaching this way is very similar to the way I normally teach. I start my lessons out with an active investigation but I now find myself thinking more about the steps and the sequence of the lesson. The process of using a phenomenon is so engaging for the students and I love teaching this way.

Our current science curriculum does not lend itself to this format of a lesson. The curriculum doesn't give us few investigations to do with our students.