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Multiple case studies of STEM teachers' orientations to science teaching through engineering design

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MULTIPLE CASE STUDIES OF STEM TEACHERS' ORIENTATIONS TO SCIENCE TEACHING THROUGH ENGINEERING DESIGN

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TABLE OF CONTENTS

Page

Page

LIST OF TABLES

LIST OF FIGURES

OVERVIEW

The following master's thesis is composed of two manuscripts. The first manuscript (Chapter one) illustrates a single case study conducted with a sixth grade STEM teacher participating in the Science Learning through Engineering Design (SLED) partnership. The second manuscript (Chapter two) describes a comparative case study of two sixth grade SLED participants. The framework guiding both studies was science teaching orientations, a component of pedagogical content knowledge.

Chapter one, "A case study of an elementary teacher's orientations to science teaching through engineering design" outlines a detailed picture of Diane's goals, practices, assessments, and general views when teaching science through engineering design. Common themes across Diane's instruction were used to characterize her orientations to science teaching through engineering design. Overall, Diane's orientations showed a shift in her practice from didactic to student-centered methods of teaching as a result of integrating engineering design-based curriculum.

The comparative case study of Olive and Cecelia presented in Chapter two revealed more complex and diverse relationships between the teachers' orientations to teaching science through engineering design and their instruction. Participants' orientations served as filters for instruction, guided by their divergent purposes for science teaching. Furthermore, their orientations and resulting implementation were developed from knowledge gained in teacher education, implying that teacher educators and researchers can use this framework to learn more about how teachers' knowledge is used to integrate engineering and science practices in the K-12 classroom.

CHAPTER ONE: A CASE STUDY OF AN ELEMENTARY TEACHER'S ORIENTATIONS TO SCIENCE TEACHING THROUGH ENGINEERING DESIGN[1]

Abstract

With the recent push for national and state science standards focusing on engineering practices in the K-12 science classroom, it becomes imperative that teachers develop the pedagogical content knowledge necessary to use the engineering design process in their science classroom. Orientations toward science teaching, a component of pedagogical content knowledge, encompass a domain of research that characterizes a teachers' general perspective on the purposes for science instruction and is typically measured by investigating a teacher's goals and instructional practices. This paper utilizes a case study approach to describe a sixth grade science teacher's goals, practices, and general views about science teaching when implementing engineering design-based tasks. By examining the teacher's purposes for instruction and observing the pedagogical methods employed in the classroom, a characterization of the teacher is formed describing her orientations towards science teaching through engineering design. Data were collected over the course of two years through semi-structured interviews, classroom observations, implementation plans, and written reflections. Data were analyzed using a case study methodology with emphasis on coding and triangulating all

[1] Rupp, M. & Capobianco, B. (to be submitted).

data sets. Results from this study support the notion that teaching orientations are content and context-specific, forming uniquely to the context of science teaching through engineering design.

Introduction

In the past few years, engineering practices have gained a presence in K-12 science education reform documents and national science standards (NGSS Lead States, 2013; National Research Council [NRC], 2012). This recent push for engineering design-based instruction and curriculum in the K-12 classroom means that in-service teachers who have not been exposed to engineering design-based teaching will need professional development and support opportunities in order to integrate design-based pedagogies effectively for student learning. Along with engaging in professional development and integrating new curricular materials, teachers are faced with the responsibility of developing their knowledge to teach science in an unfamiliar engineering design-based context. The focus of this study is a sixth grade science teacher's construction of knowledge when learning how to teach science through engineering design.

Orientations have been found to be context and topic-specific; therefore, it may be hypothesized that teachers will have unique orientations toward science teaching when using engineering design-based instruction (Cheung & Ng, 2000). Researchers may ask: What practices are science teachers using and how do they set goals for instruction in the context of engineering design? What novel teaching orientations emerge within this context that may be different from those that emerge from inquiry or traditional science instruction? In the study we attempt to: (a) define and describe the method of generating orientations toward science teaching through engineering design, (b) outline the instructional goals, practices, assessments and general views of science teaching of a sixth grade teacher implementing engineering design into her practice, and (c) describe how the teacher's goals, practices, assessments, and general views of science teaching form unique orientations to teaching science through engineering design.

The major research question guiding this case study is: What are a sixth grade science teacher's orientations towards teaching science through engineering design? By describing the teacher's orientations, we attempt to address two supporting questions: (a) what are the instructional goals, pedagogical practices, assessments, and general views expressed by the teacher? and (b) how do these components of the teacher's practice characterize her science teaching orientations in an engineering-design based context?

Theoretical Framework

The study draws largely from the literature on teacher knowledge. Shulman (1986, 1987) defines teacher knowledge as a model for teacher understanding that "distinguishes teachers from subject matter specialists" (as cited in Abell, 2007). Teacher knowledge is categorized into several domains, including but not limited to subject matter knowledge, pedagogical knowledge, and pedagogical content knowledge. For the purpose of this study, the construct of pedagogical content knowledge (PCK), more specifically the construct of teaching orientations, was examined. The scope of a teacher's knowledge has tremendous depth and breadth. Each component of teachers' pedagogical content knowledge influences the questions they ask students, the assessments they use to measure student learning, and the topics they decide to include in their curriculum among many other choices and decisions (Friedrichsen, van Driel &

Abell, 2011). Fully developed understandings of each component independently, “can serve as a conduit to enhance our knowledge of PCK” (Park & Chen, 2012, p. 923). Thus, this case study seeks to develop a thorough understanding of one component of PCK, science teaching orientations.

Teaching orientations is defined as a “general way of viewing or conceptualizing science teaching” which helps teachers make important instructional decisions in their classroom (Magnusson, Krajcik & Borko, 1999, p. 95). The most fitting definition of science teaching orientations for the purposes of this study comes from the work of Friedrichsen, van Driel, and Abell (2011): “a general way of viewing teaching science [that] connects views with teachers’ actions” (p. 366). Therefore, the teacher’s views about teaching science, expressed through her goals and purposes for instruction, were analyzed alongside her actions in the classroom.

Studies have traditionally focused on defining the components of teacher knowledge (Ball, 2000) and characterizing classroom instruction (Borko, Stecher, Alonzo, Moncure, & McClam, 2005). Research is needed in the context of science teaching through engineering design-based instruction, specifically characterizing teachers’ orientations based on their goals and practices. A detailed picture of this aspect of teacher knowledge can inform teacher educators and educational researchers of science teachers’ diverse knowledge, perspectives, goals, and ways of implementing novel curriculum that emerge in the context of engineering design.

Context of the Study

This study is part of a large scale, multi-year university-school partnership. The Science Learning through Engineering Design (SLED) partnership is a collaboration among practicing elementary school science teachers and university faculty from science, technology, engineering, and mathematics (STEM), aimed at improving grade 3-6 students' learning of science through the integration of engineering design. The SLED partnership includes participation of over fifty teachers from rural, urban, and suburban school districts in the central Midwest. Teachers participate in an intense, content-rich professional development program in the summer where they engage in authentic, grade appropriate, standards- and engineering design-based science tasks, prepare multi-day implementation plans, and collaborate with STEM faculty. Throughout the school year, teachers test out their ideas, assess students' engagement in the design tasks, and reflect on their attempts at integrating engineering design-based instruction. Simultaneously STEM faculty, in the form of design teams, work collectively with the practicing teachers to generate new engineering design-based lessons, pilot test their activities, and consult with SLED teachers to revise and refine their tasks for incoming teachers. Instructional products from the SLED partnership include an electronic repository of classroom tested, standards- and engineering design-based tasks, assessments, and teacher reflections.

The Engineering Design Process

Underpinning this study is the role of the engineering design process in the elementary science classroom. Each task is grounded in a five-phase iterative process. Students are introduced to the process in the form of a design brief. The brief represents a narrative of a plausible scenario or situation in which students are asked to solve a problem using the engineering design process (Dankenbring, Rupp, Capobianco, 2013). Embedded in the design brief is a description of the context of the problem that includes a targeted end user, a client who needs help, a description of the problem that needs to be addressed, and a list of requirements for the design. Students are given a limited number of materials and resources, a fixed amount of time, and specific parameters or guidelines to follow. Once students identify the essential features of the problem, they then plan individually. Students then share their plans with other members of a design team. As a team, students come to a consensus on a unified plan and then begin the construction of the team's design. The team tests, re-tests, and communicates results from testing. After communicating, the design team redesigns in an effort to improve its designs.

Study Participant

The teacher participant in this case study was purposefully selected (Patton, 2005) from a larger study population that included twenty-nine grade five and six STEM teachers. Diane Church (a pseudonym was used to protect the anonymity of the participant) was selected for this study based on the following criterion: (a) she was a teacher who was interested in reflecting about her experiences; (b) she allowed members of the researcher team to observe her practice closely for two years, and (c) she provided detailed and reflective responses to interview questions. Patton (1990) describes this kind of participant sampling as purposeful sampling because "individuals or cases are selected that provide the information needed to address the purpose of the research" (as cited in Johnson and Christensen, 2012, p. 235). Due to the rich, descriptive nature of the case study, it was important to choose a teacher who was willing to discuss, at length, her attempts at implementing multiple engineering design tasks.

Diane Church was a sixth grade science teacher in an urban intermediate school located in the central Midwest. Schoefield Middle School (pseudonym) housed over 1,000 grade five and six students. The enrollment of students in the first year of the study was 495 grade five and 513 grade six students (total=1,008). The demographics of the student population was 5.7% multiracial, 0.6% American Indian, 13.4% black, 20.7% Hispanic, 0.5% Asian, and 59.1% White (Indiana Department of Education [INDOE], 2013). In the second year of the study, enrollment was 547 grade five and 496 grade six students (total=1,043). The demographics of the student population in the second year include: 5.0% multiracial, 0.7% American Indian, 12.9% black, 0.5% Asian, 23.7% Hispanic, 57.2% White (INDOE, 2013). Diane began the study in her fourth year of teaching. At the time of the study, Diane's students were classified as "academically gifted," performing at a higher level than the school population.

In the first year of data collection, Diane integrated two engineering design tasks entitled Take a Stand and Roller Coaster. In the second year, Diane increased her implementation to four design tasks including: Reindeer Habitat, Solar Tracker, Roller Coaster and Bottle Racers (See Table 1).

Schoefield Middle School required their STEM teachers to follow a school-wide, common curriculum calendar which Diane followed during her implementation. The fall semester was devoted to life science topics and the spring semester to earth and physical science topics. Therefore, she purposefully chose tasks that aligned with the state academic science standards and the prescribed school calendar. Diane described her instruction before integrating engineering design tasks as having a focus on textbook readings, worksheets, and recall of science knowledge.

Table 1.

Overview of engineering design tasks

Title	Purpose of Design Task	Related Science Concepts or Practices
Take a Stand	Design and construct a structure to hold a shot put	Tension, torsion, compression, load
Roller Coaster	To design and construct a roller coaster that results in the greatest total loop diameter at the lowest cost.	Potential energy, kinetic energy, conservation of energy, friction
Reindeer Habitat	Create a plan for a reindeer habitat at a local zoo	Producer, consumer, habitat, biotic factor, abiotic factor, population, food chain
Solar Tracker	Develop a solar panel system that can be easily moved to track the sun, so that the panel can collect as much solar energy as possible	Axis, solar, solar panel, direct rays, indirect rays
Bottle Racers	Design a car from a plastic bottle that will be powered from an energy source	Kinetic energy, potential energy, chemical reaction, chemical energy

Source: www.sledhub.org

Methodology

Johnson and Christensen (2012) define case studies in the simplest of terms: "research that provides a detailed account and analysis of one or more cases" (p. 395). The case study method is not distinct from other qualitative research because of the type of data collected (interviews, surveys, documents, etc.); rather, a case study is unique because "whatever techniques are used, all are focused on a single phenomenon or entity (the case) and attempt to collect information that can help understand or interpret the focus of the study" (Ary, Jacobs, Sorensen & Razavieh, 2010). By focusing on one specific person, situation, or context (the case), research within case studies allows for "rich detailed accounts of phenomena" (Ary et al., 2010).

This study utilizes a case study research design with an interest in "process rather than outcomes, in context rather than a specific variable, in discovery rather than confirmation" (Merriam, 1998, p. 19). In other words, the purpose of this case study was to present a detailed description of a teacher's goals and instructional practices and inductively identify recurring themes in the relationship between her goals and instruction. Specifically, these relationships that emerged between Diane's instructional goals and practices revealed her science teaching orientations within the context of engineering design. In this case, the context of her instruction was pertinent, helping the researcher develop the "particularity and complexity of a single case, coming to understand its activity within important circumstances" (Stake, 1995, p. xi).

Data Collection

Data were collected over two academic years during Diane's implementation of engineering design-based tasks with the Science Learning through Engineering Design (SLED) partnership. Data sources included semi-structured interviews, classroom observations, post-observation interviews, written reflections, implementation plans, and reflection sessions with her colleagues. What follows is a brief description of each data source. Figure 1 illustrates the timeline of data collection over the course of both academic years.

Semi-Structured Interviews

At the beginning and end of each academic year, Diane was interviewed about her plans for and reflections on implementing design tasks, how the tasks fit into her curriculum, anticipated and experienced challenges, and her conceptions of engineering design-based instruction. A total of four semi-structured interviews lasting approximately 30-45 minutes were conducted over two years.

Focus Group Interview

During year one of data collection, one focus group interview was conducted with three SLED participants, including Diane, at Schoefield Middle School. This interview was conducted following Diane's implementation of Take a Stand and allowed her to reflect on and discuss her first integration of engineering design in her classroom while hearing more about similar efforts in her school.

Classroom Observations and Post-Observation Interviews

Classroom observations in the form of detailed field notes were compiled, coded, and used to compose post-observation interview protocols. Interview questions focused on how Diane attempted to meet her goals for instruction, what she felt was most important for her students to learn, and which strategies she preferred to use while teaching a particular unit or related concepts. During year two of data collection, a series of multi-day classroom observations and post-observation interviews were conducted for each respective task.

Implementation Plans

Diane participated in a summer professional development institute designed to prepare fifth and sixth grade teachers to implement engineering design-based tasks in their science classrooms. During the institute, the participating teachers were guided through design-based lesson plans prepared by university faculty and spent several days planning lessons for the coming academic year with their colleagues. From this planning process, the teachers created multi-week implementation plans outlining their objectives, standards, activities, and assessments for each task. A total of two implementation plans were generated in year one and four implementation plans in year two.

Written Reflections

In the second year of the study, Diane prepared two electronic reflections: one regarding her experiences with Reindeer Habitat and a second about Solar Tracker. Diane was prompted to reflect on the task, focusing on improvements and changes she would make if she implemented the tasks again and descriptions of students' work from her class at different performance levels.

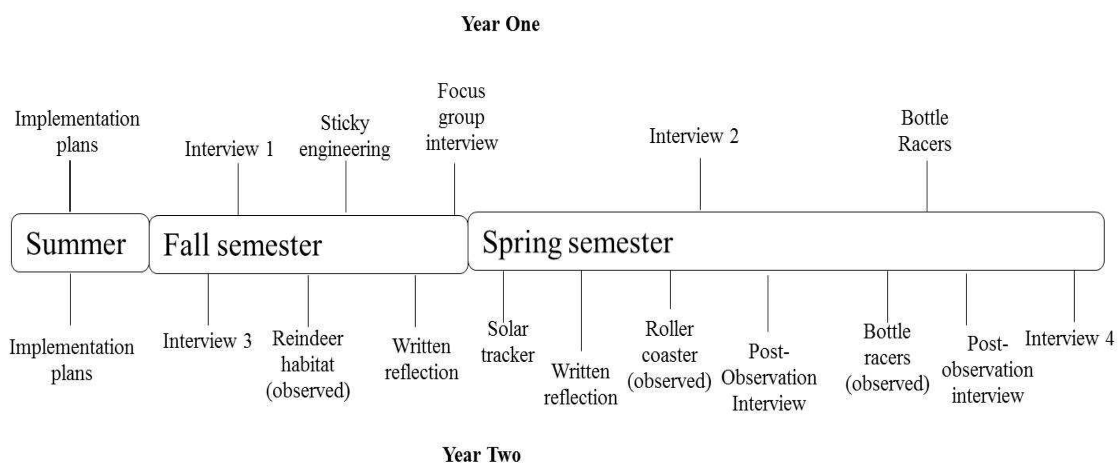

Figure 1. Timeline of data collection

Data Analysis

The process of data analysis closely followed that briefly and simply outlined by Patton (2005): assembled the raw case data; constructed a case record; and prepared a final case study narrative. A case record is a compilation of all the relevant raw data into one "resource package" to be used for analysis and writing (Patton, 2005, p. 449). In this study, each data source was compiled into a chronological case record for analysis. The data were inductively coded within four major domains: the teacher's (a) goals for instruction and student learning; (b) planned and enacted pedagogical practices; (c) planned and enacted methods of assessment and (d) general views of science education in the context of engineering design. Recurring themes which occurred across all four domains were collapsed into plausible orientations. These orientations were then prioritized based on the frequency of occurrence in the data set yielding two differing hierarchical characterizations of Diane's science teaching through engineering design.

Figure 2 represents the interconnected relationships between a science teacher's orientations and his/her instructional goals, pedagogical practices, planned and enacted assessments, and general views of science teaching in the context of engineering design. As demonstrated by the graphic representation, Borko and Putnam (1996) describe orientations as "filters" for a teacher's decision making in her classroom (as cited in Rogers, Cross, Gresalfi, Trauth-Nare & Buck, 2011, pp. 894). Science teachers' orientations while enacting problem-based learning (PBL) for the first time were found to guide "the ways in which they organized their classrooms, designed projects, interacted with students, and sought to enact PBL principles" (Rogers et al., 2011, pp. 909). Similarly, Diane's orientations were conjectured to act as a filter through which she decided to set goals for instruction, plan and enact various instructional strategies, evaluate student performance, and express her ideas about science teaching through engineering design.

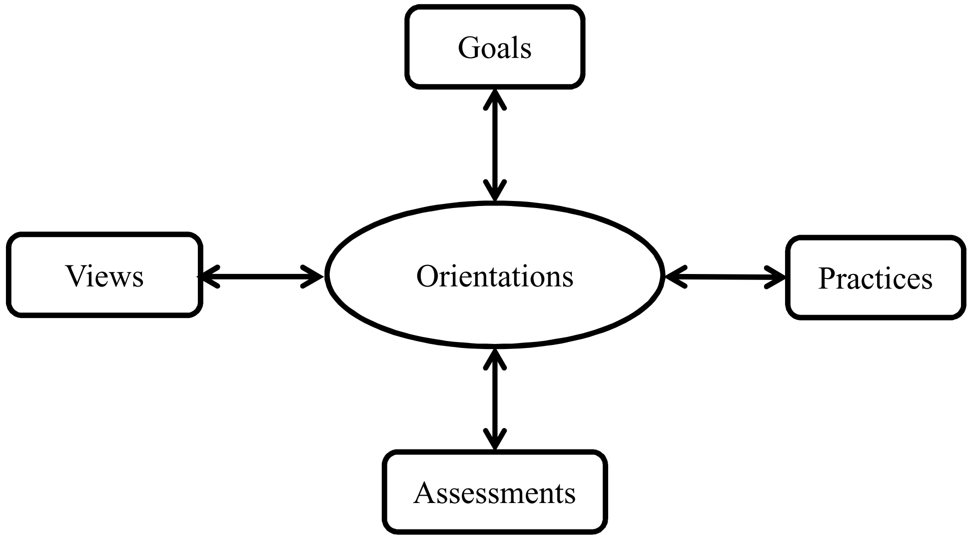

Figure 2. Orientations and four domains of influence (Borko & Putnam, 1996).

Results and Discussion

Diane's goals and objectives, instructional practices, plans for assessment, and general views of science education in the context of engineering design revealed two recurring themes in her science teaching in the context of engineering design: 1) application of scientific concepts, and 2) hands-on collaborative activities. These two themes are called *orientations* because they reveal unique ways in which Diane draws from her knowledge of teaching in order to implement engineering design tasks in her curriculum. The following section outlines and explains these respective orientations in detail.

Primary Orientation: Application of Science Concepts

Diane's primary orientation toward science teaching through engineering design is *application of science concepts.* This assertion is based upon how she articulated and enacted the respective design tasks. Interview and classroom observation data indicated that Diane was focused on students' articulation of key science concepts. In particular, data indicated that Diane viewed engineering design as a method of allowing students to predominately apply the science knowledge they learned to either science-driven conversations or presentations about the students' designs.

According to Diane, her primary influence for this orientation was the state academic science standards and school science policies. Frequently referencing the school-wide curriculum map and the content standards for her state, Diane focused on making sure the students understood the science concepts which were directly related to the science standards. For example, when asked what was most important for her students to learn from the Roller Coaster design task, Diane explained, "The sixth grade content standards is dealing with energy transformation, so the transfer from potential to kinetic energy and that, I think, is the most important because it relates directly back to the standards that we have to address this year" (Post-observation interview, Spring 2013).

Instructional goals. Diane expected her students to use science concepts to justify the design of their prototypes and assessed the students' use of these concepts when explaining their plans to teammates in conversations and when presenting to the class. Her instructional goals expressed in implementation plans and interviews included that her students "understand the science concepts" and "apply the science concepts to a design task."

Classroom practices. Diane's use of instructional strategies based on recall of scientific and engineering design concepts played a key role in her teaching within this orientation. Diane used class activities such as vocabulary games on a Smart Board© and whole class discussions to front-load the science information before students started a design task. In light of her choice of instructional strategies and resources, this orientation is somewhat didactic. Diane stated in her earliest interviews that her teaching focused primarily on the use of "bookwork." Specifically she stated: "I have a lot of supplemental stuff that I use but, you know, it's reading and answering so it doesn't really go much beyond the knowledge, recall, and stuff" (Interview 4, Fall 2013). Although Diane described this type of teaching as a method of the past, she was observed utilizing more traditional, book-related strategies on several occasions.

Assessment of student performance and learning. Diane focused on her students' use of science vocabulary (written and verbal) when student teams discussed and presented their prototypes. Less frequently, she referenced application of science concepts as knowledge that students could use to inform their designs or the results from testing their designs to make them more effective. In her implementation plans, Diane identified students' design notebooks as an artifact to evaluate student performance. In her plans she proposed to determine frequency counts of key science terms used by students rather than evaluate the overall quality of her students' conceptual understandings of the terms.

General views of science teaching through engineering design. Engineering design seems to be on the periphery of Diane's classroom teaching within this orientation. Instead of facilitating students' construction of new scientific knowledge during or as a result of design, Diane spent considerable time conversing with students about what science concepts applied to their designs. There is a unique difference between the way science is typically utilized in "design-based science" and the way Diane utilized science in her practice (Fortus, Dershimer, Krajcik, Marx and Mamlock-

Naaman, 2004). According to Fortus et al. (2004), the purpose of design-based science is not to have students apply scientific knowledge in a culminating design task; instead, science in authentic design-based teaching is “constructed in the context of designing artifacts as particular instances of solving ill-defined, real-world problems” (p. 1082).

During her written reflection on Reindeer Habitat in her second year, Diane shared the following: “Spending time at the beginning of each lesson/day discussing reindeer, sharing artifacts, referencing research was extremely beneficial. Not only was it a great review, but it kept the design task on track with the second nine week unit, Life Science” (Reflection, Fall 2012). Here Diane is referring to her construction of scientific understandings before a design task through research and the applications of these understandings through the sharing of the students’ artifacts or prototypes.

In other words, in her classroom, the purpose of science in engineering design was not necessarily to inform the students’ plans, designs, or prototypes, but to use the science concepts through “intelligent conversations” with other students (Interview 3, Fall 2012). Embedding the science and engineering design concepts into the design-based class discussions remained Diane’s goal and it was a common practice she wanted to improve. She stated: “I love to hear the students using the vocabulary and concepts more within their own conversations…I want to look for ways to motivate my students to use the terminology, which in the end will definitely help them to master the science concepts that will be assessed at the end of the year” (Reflection, Fall 2012). In sum, Diane placed more emphasis on students’ usage of concepts in conversations rather than students’ construction of science conceptual knowledge through the engineering design process.

Her words imply a noticeable separation between engineering design and science concepts with the intention of embedding them more in future implementations.

Secondary Orientation: Hands-On Collaborative Activities

Diane's secondary orientation was similar to the *activities-driven orientation* found in the literature on elementary school teachers' science teaching orientations (Anderson & Smith, 1987). According to Friedrichsen, van Driel and Abell (2011), this orientation which focuses on the teachers' goal of having students be active with materials, is lacking empirical backing. Hence, Diane's *hands-on collaborative activities* orientation may contribute to the research on this type of orientation. Diane stated, "I think students really begin to understand the vocabulary when they can put it into action, if you will […] that's when vocabulary comes to life for my students and makes sense to them" (Interview 3, Fall 2012). In other words, Diane's *hands-on collaborative activities* orientation was based on the idea that when students participate in active learning (i.e. getting out of their seats and manipulating materials) within teams, they become more engaged and understand science concepts.

Diane often discussed hands-on activities and student collaboration as components of her classroom instruction that were enjoyable for her to observe and for her students to participate. In other words, hands-on, collaborative activities were a type of instruction that Diane sought to share with her "higher-ability" students because they "really eat these things up" (Interview 3, Fall 2012).

Instructional goals. Diane's goals within this orientation include her students learning to work together to solve a problem and learning how to communicate with teammates. For example, in her second year implementation plan, Diane indicated "teamwork" and "learning how to work together" as important skills for her students to exercise when engaging in design.

Classroom practices. Diane's conceptions and use of the engineering design process reflected engineering design as a step-by-step process, with each phase of the process representing its own individual activity to be completed before starting the next one. Furthermore, Diane modified her students' engineering design notebooks by creating a worksheet packet that separated the design process into individual steps with explicit directions and designated boxes for recording drawings and responses. In this way, design was presented from a procedural standpoint, with Diane often teaching isolated design phases each class period or lesson. When asked what she learned at the professional development institute in the summer before participating in the partnership, Diane described learning some "exciting new activities" to implement in her classroom. Her conception of design-based curriculum as activities-driven became transparent in classroom observations where Diane employed a more technical approach to teaching design, viewing her implementation of the design tasks in a segmented, step-wise form.

Assessment of student performance and learning. Within this orientation, Diane focused on evaluating her students' participation in class discussions, completion of their engineering design packet, and working together in design teams. In her implementation, she often began the class by reminding her students that the design tasks were a "major project grade" and emphasized that students needed to take the activity seriously by completing all steps of the design task packet.

General views of science teaching through engineering design. Diane's conceptions of the engineering design process were described as "a process that allowed her students to share their ideas in order to come up with the best design." Diane stated: "that's the neatest part of the engineering design process and that's what you would see when you walk into my classroom." According to Diane, the tasks were characterized as "hands-on, collaborative learning experiences" that were "beneficial for her students" (Interview 3, Fall 2012). Diane's *activities-driven* orientation extended beyond that found in previous research by focusing not only on keeping students active, but instead utilizing the activities as tools to enhance students' understandings of science concepts through team collaboration.

Diane also implied that engineering design activities were an integral part of her students learning how to work together. She often gave explicit expectations for the students working in teams throughout the process, including skills such as professionalism and sharing equitable roles within a team. Without design-based tasks, she indicated that her students would not know how to collaborate as a team in that particular grade level, even though her students were labelled as academically gifted.

Conclusions

The purpose of the study was to characterize a sixth grade teacher's science teaching orientations in the context of engineering design. Two orientations were developed from interviews, observations, implementation plans, and written reflections with Diane. These orientations included: (a) application of science concepts and (b) hands-on, collaborative activities. This study attempted to capture Diane's orientations in a specific context, teaching science through engineering design-based activities, in order to shed light on particular circumstances that may alter a teacher's general views and purposes for teaching science. Results of this study indicated that Diane's orientations to science teaching shifted during her implementation of engineering design tasks. Although some of her classroom practices and assessments remain more closely aligned with her teaching before implementation, the majority of her instruction began to transition to less didactic orientations as a result of developing knowledge of science teaching through engineering design. In other words, through the introduction of engineering design-based science instruction, Diane generated new pedagogical knowledge thereby extending her existing orientations toward science teaching to include emphasis on the role of science concepts and hands-on activities in her practice. These results further indicated that characterizing teachers' orientations is complex, particularly when orientations have been found to be context specific. As Diane's circumstances and expectations changed, developed, and matured, so did her orientations. The teacher in this study exhibited multiple views of science teaching unique to the context of engineering design-based instruction, enabling the teacher to access specific areas of her knowledge base that were not usually explored with more traditional methods of science teaching.

For example, Diane's primary orientation towards applying science concepts was largely developed through the use of engineering design tasks. Forming a solution to an authentic problem gave Diane's students the tools they needed to solidify and use their scientific knowledge in a culminating activity. She stated that prior to implementing engineering design, she taught predominantly from the textbook and other readings. Although some classroom practices, such as the use of vocabulary matching games and graphic organizers, closely resembled Diane's preferred methods of teaching before design-based instruction, her implementation of design tasks as a method of extending and applying what the students' learned was evidence of a shift in her practices. With more targeted professional development and teaching experience, results of this study indicated that Diane could continue to transition her practices, abandon almost all didactic methods of teaching science, and allow her students to fully construct conceptual understandings through the implementation of design tasks.

From her secondary orientation (hands-on collaborative activities), Diane was able to modify her practice from a traditional form of instruction to a more hands-on, exploratory approach. Diane's views of science teaching through engineering design offered a perspective of design tasks as a method of engaging students in active learning projects. As a result, an orientation emerged that indicated a stronger emphasis on increasing collaboration among her students using design-based instruction.

Implications

Results from this study have important implications for the work of science education researchers and science teacher educators. Science education researchers, especially those invested in the integration of engineering practices in the K-12 classroom can benefit from knowledge developed about science teaching orientations within a design-based context. Science teacher educators may utilize the insight gained from an inservice teacher's experiences and knowledge development while attempting to adapt her curriculum to align with current academic expectations.

Diane's context-specific orientations provide valuable information for science education researchers examining the components of teacher knowledge, specifically science teaching orientations, within an engineering design-based context. Researchers suggest that orientations have been used too differently, are not clearly defined in the literature, and lack empirical evidence (Friedrichsen, van Driel & Abell, 2011;

Magnusson, Krajcik & Borko, 1999). In light of these critiques, identifying and examining science teachers' orientations within design is critical in terms of clarifying the construct of teaching orientations and using the evidence of this research to expand the research base of teacher knowledge development in K-12 engineering design-based instruction.

The detailed knowledge gained in Diane's implementation of engineering design tasks is helpful to science teacher educators examining the dispositions teachers must have when implementing novel, reform-based practices. Attention must be given to what kinds of new knowledge science teachers can construct in the context of engineering design-based instruction and how science teachers can accommodate and assimilate this new knowledge within their existing and potentially new orientations for teaching science. With in-depth study of science teachers' current purposes and views, effective shifting of practices could occur with targeted professional development, making reform efforts with the inclusion of engineering design in the K-12 classroom more impactful.

In summary, illuminations of a teachers' orientations toward science teaching through engineering design is pertinent information for science education researchers to examine the knowledge necessary for implementing design-based activities and for science teacher educators to enhance learning opportunities for in-service and pre-service teachers faced with new expectations for their practice.

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CHAPTER TWO: A COMPARATIVE CASE STUDY OF TWO STEM TEACHERS' SCIENCE TEACHING ORIENATIONS IN THE CONTEXT OF ENGINEERING DESIGN[2]

Abstract

The purpose of this comparative case study was to explore two sixth grade STEM teachers' experiences when implementing engineering design into their classrooms. The study is guided by literature on teacher knowledge, specifically teacher's orientations. Data were gathered via implementation plans, semi-structured interviews, classroom observations, pre- and post-observation interviews, and written reflections. Data were analyzed using a two-phase comparative case study approach. First each teacher's individual goals, assessments, views, and practices were analyzed to form science teaching orientations specific to the context of engineering design. In the second stage of analysis, the teachers' orientations and classroom instruction were compared. Results indicated that teachers choose diverse ways to integrate engineering practices in their classrooms that often align with science education reform. The significance of this study is that teacher's orientations (i.e. general views and practices) toward science teaching through engineering design provide valuable information about the knowledge teachers use to enhance their instruction. Implications of this work suggest that more research is needed regarding the knowledge teachers employ when integrating design-based

[2] Rupp, M. & Capobianco, B. (to be submitted).

practices. This information is valuable for teacher development because it reveals teachers' views and practices that need to be targeted for effective science education reform.

Introduction

National science education reform documents such as *Next Generation of Science Standards* (NGSS Lead States, 2013) and *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Research Council [NRC], 2012) have made significant suggestions for reforming and transforming science education. In particular, the integration of science and engineering practices is the most notable and controversial addition to these reform documents. The inclusion of practices from both disciplines was intended to support "a better understanding of how scientific knowledge is produced and how engineering solutions are developed" (NRC, 2012, p. 41).

Much research has been done even before the publications of these reform documents to examine the presence of engineering in the K-12 classroom. In particular, past research has contributed to the understanding of how science and engineering conceptual understandings can be constructed in an engineering design-based setting (Fortus, Dershimer, Krajcik, Marx, Mamlok-Naaman, 2004; Fortus, Krajcik, Dershimer, Marx & Mamlok-Naaman, 2005; Lewis, 2005). More presently, in response to recent reform documents, practitioner-based literature about engineering design in the K-12 science classroom has focused on the materials and resources needed to develop and enact standards- and design-based curriculum (Bybee, 2011; Crismond, 2013; Krajcik & Merritt, 2012). However, few research studies have been conducted since the publication of these reform documents examining how inservice teachers choose to adapt their curriculum in light of the integration of science and engineering practices in science education (Hynes, 2012). More specifically, research has yet to develop in-depth, practical information about how teachers use their knowledge and views about science education to achieve the integration of science and engineering practices. This type of research is important because as K-12 science teachers begin to implement engineering practices into their classrooms, they will inevitably either develop a new knowledge base or extend an existing knowledge base within this context.

The aim of this comparative case study is to fill this gap in science education research by exploring and characterizing elementary STEM teachers' experiences with implementing engineering-design based curriculum. By presenting detailed and comparative cases of STEM teachers' orientations toward science teaching through engineering design, insights can be developed into what kind of knowledge and perspectives teachers utilize in their attempts to meet new national standards. Results of this study are significant because they unveil what teachers and teacher educators need to know to authentically and effectively integrate science and engineering practices in the next generation of science classrooms.

Purpose of the Study and Research Questions

The purpose of this case study was to identify, describe, and compare the science teaching orientations of two elementary teachers implementing engineering design-based curriculum. Three research questions helped guide this comparative case study:

1. What are elementary teachers' orientations toward science teaching in the context of engineering design?

2. How do the teachers' orientations compare to one another?
3. In what ways do the teachers' orientations for teaching science through engineering design influence their science instruction in a design-based setting?

Theoretical Framework

The theoretical framework guiding this study is science teaching orientations, a subcomponent of pedagogical content knowledge (PCK). PCK is an aspect of a teacher's knowledge which is considered to encompass five domains including knowledge of science learners, science curriculum, science instructional strategies, science assessments, and orientations toward teaching science (Abell, 2007). Studies have used PCK and its components as a framework to characterize teachers' instruction of several subject areas (Hynes, 2012; Park & Chen, 2012).One specific component of PCK has been referred to as teachers' orientations (Abell, 2007; Friedrichsen, van Driel & Abell, 2011). Orientations toward teaching science have been defined in the literature as a "teachers' knowledge and beliefs about the purposes and goals for teaching science at a particular grade level" (Magnusson, Krajcik & Borko, 1999, p. 96-97). What follows is a description of the features characteristic of teachers' orientations and their application in this study. These features include the following: (1) methods and purposes of characterizing teachers' instruction, (2) the development of science teaching orientations, and (3) defining science teaching orientations.

Methods and Purposes of Characterizing Teachers' Instruction

Characterizing teachers' instruction, practices, and views has the potential to contribute significantly to efforts in reform-based research and professional development. Teaching characterizations have been used within several domains of educational research including English education (Grossman, 1990), technology use (Campbell, Longhurst, Duffy, Wolf & Shelton, 2013; Law, 2009); inquiry-based science instruction (Eick & Reed, 2002; Ramnarain & Schuster, 2014); problem-based math and science learning (Rogers, Cross, Gresalfi, Trauth-Nare & Buck, 2011); and the engineering design process (Hynes, 2012). Specifically within science teaching, characterizations of teachers have been used to provide information about national and international reform efforts (Dani, 2009; Levitt, 2002; Nargund-Joshi, Rogers & Akerson, 2011); impacts of teacher professional development (Campbell, et al., 2013); curriculum innovation (Smith and Anderson, 1984); and diverse contextual influences on instructional approaches (Ramnarain & Schuster, 2014). According to Levitt (2002), science education reform requires not only a change in teaching practices but a shift in the way teachers think about the way science should be taught and learned. Therefore, a teacher's views on science teaching and learning, a component of science teaching orientations, may help to determine impacts of science education reform.

The use of teaching orientations is an ideal framework for guiding teaching characterizations because they reveal the various purposes that teachers may hold for implementing curriculum the way that they do (Magnusson et al., 1999). Some methods of eliciting science teaching orientations include but are not limited to the Pedagogy of Science Teaching Test (POSTT) (Cobern, Schuster, Adams, Skjold, Muğaloğlu, Bentz & Sparks, 2013; Ramnarain & Schuster, 2014) and a classroom vignette card-sorting task (Friedrichsen & Dana, 2003; 2005). The POSTT was used to categorize teachers according to "instructional type" (e.g. didactic direct, active direct, guided inquiry, and open inquiry) and then place them on a four-quadrant "teaching orientation spectrum" which mapped out the teachers' instructional type as well as type of student learning—rote or meaningful (Ramnarain & Schuster, 2014, p. 6). Friedrichsen and Dana's (2003) card-sorting task was an "elicitation and clarification tool" used to generate a summary of the teacher's "purposes and goals" within their "current science teaching orientation" (p. 302). Both the POSTT and the card-sorting instruments utilized classroom vignettes describing science instruction to elicit teacher responses and help to articulate some aspects of a teacher's single orientation.

These methods, although effective, do not provide detailed profiles and descriptions of teachers' knowledge and beliefs about science teaching and are fairly prescriptive. The use of predetermined orientations does not leave room for the explication of novel orientations in new contexts. Furthermore, teachers have been found to hold more than one, single orientation (Friedrichsen et al., 2011). In actuality, science teaching orientations are quite complex and difficult to characterize (Friedrichsen et al., 2011; Nargund-Joshi et al., 2011). Therefore, a descriptive and comparative case study approach guided by a contextually inclusive definition of science teaching orientations was used in this study to characterize teachers' science instruction through engineering design.

The Development of Science Teaching Orientations

The construct of science teaching orientations has evolved from research on teacher knowledge (Shulman, 1986, 1987) and pedagogical content knowledge (Grossman, 1990). The term "science teaching orientations" has not always been labelled as such. Beginning with Grossman's descriptions of pedagogical content knowledge, one component was described as the teacher's "beliefs about the goals for teaching their subject" which provide a "conceptual map for instructional decision making" (Grossman, 1990, p. 360). This domain of PCK has since been defined by Magnusson et al. (1999) as orientations to science teaching, combining the work of Grossman (1990) and Smith and Anderson (1984). The importance of including Anderson and Smith's (1987) perspective on science teaching orientations is centered on the role of a teacher's behavior as shown through instructional choices and priorities. In other words, the construct defined by Magnusson, et al. (1999) purported to include the teachers' classroom practices and strategies alongside their goals and beliefs thereby making it possible to examine a teacher's goals *and* practices to characterize their orientations. However, since these definitions have emerged in the literature, some issues have arisen with their use (Friedrichsen et al., 2011).

One critique of teaching orientations in past research is that the term is often used without clearly defining how it is being utilized or similar constructs are used absent of the term orientations (Friedrichsen et al., 2011). For example, researchers have used the construct and/or the term science teaching orientations to characterize many aspects of science teaching including priorities for student learning (Smith & Anderson, 1984), purposes for teaching science (Dani, 2009), and curricular emphases (Roberts, 1982). Although these studies are helpful in providing a picture of the teacher's instruction, "it would benefit the field to more deeply understand the existing constructs [of science teaching orientations]" if a "cohesive research agenda" is laid out (Abell, 2007, p. 1124-1126).

A second critique of science teaching orientations is that teachers are often assigned only one orientation from a predetermined list of possibilities (Friedrichsen et al., 2011; Magusson et al., 1999). Magnusson and colleagues (1999) have generated a comprehensive list of nine science teaching orientations. Missing from this domain of work are studies that expand or enhance this cursory knowledge base of science teaching orientations and further propose new dimensions or features of teachers' orientations to science teaching within new contexts of reform-based teaching (i.e., engineering design-based science teaching).

Defining Science Teaching Orientations

In response to critiques of ambiguous use of science teaching orientations, researchers have attempted to more clearly define the dimensions and components that determine a teacher's orientations (Friedrichsen et al., 2011). Some dimensions of science teaching orientations used in research include a teacher's beliefs about (1) the goals or purposes of science teaching, (2) the nature of science, and (3) science teaching and learning (Friedrichsen, et al., 2011; Campbell et al., 2013). Furthermore, teachers' orientations to teaching science are said to shape the teacher's knowledge of science curricula, assessment of science literacy, instructional strategies, and students' understanding of science (Magnusson et al., 1999, p. 99). Magnusson and colleagues (1999) examined two facets of pedagogical content knowledge in order to differentiate a science teacher's orientation: (a) the goals of teaching science that a teacher with a particular orientation would have and (b) the typical characteristics of the instruction that would be conducted by a teacher with a particular orientation (p. 97). For the purpose of this study, these two facets are examined along with two other facets of PCK in order to obtain more distinctly described orientations. The two other facets of the teachers' instruction included their general views about science teaching through engineering design and their purposes for their instructional decisions and choices.

Important for this case study was this characteristic of science teaching orientations: "it is not the use of a particular [teaching] strategy but the *purpose* of employing it that distinguishes a teacher's orientation to teaching science" (Magnusson et al., 1999, p. 97). For example, two high school chemistry teachers may both implement a cabbage juice pH indicator lab but their purposes for using the lab may differ. One collaborative activities-oriented teacher may hope to keep her students engaged in a hands-on lab experience. Another inquiry-oriented teacher may be driven by their belief that inquiry-based practices are an integral part of science instruction. In other words, the teachers' orientations were not defined by their instructional choices alone; their respective science teaching orientations—collaborative activities and inquiry—were defined by their purposes (i.e. intentions) for their chosen teaching strategies. These purposes emerge from many components of the teachers' instruction implicitly and are therefore determined inductively by examining their instruction, assessments, views, and goals (i.e. stated instructional objectives).

Descriptive profiling of teachers and their instruction using the construct of science teaching orientations warrants a clearly defined means of characterization. For example, researchers examining a project-based learning approach to science teaching used science teachers' orientations as a framework for mapping the focus of three teachers' math and science instruction (Rogers et al., 2011). By clearly defining their use of teaching orientations, their study contributed both to the literature on teacher knowledge and problem-based learning. In a similar vein, the aim of this study is to simultaneously clarify the research on the components of teacher knowledge (teaching orientations) and engineering design-based science instruction through the examination of teachers' attempts to implement design tasks into their science classroom. By elucidating teachers' instructional goals, pedagogical strategies, assessments of student learning, and views of science teaching while focusing on their purposes for instructional decisions within a design-based setting, informative profiles of STEM teachers can be formed. These profiles can inform researchers of the knowledge and views teachers use when integrating science and engineering practices.

Context of the Study

Science Learning through Engineering Design

The Science Learning through Engineering Design (SLED) Partnership is a large scale, multi-year collaboration among university STEM faculty and inservice elementary school science teachers aimed improving student learning of science through engineering design. Teachers learn about the engineering design process, engage in engineering design-based tasks, and reflect on their experiences during an intense summer program. Teachers then prepare multi-day implementation plans that illustrate how they plan to integrate these respective tasks within their own classroom practice. As teachers implement, they reflect on their attempts and adjust their practice to accommodate for students' needs, statewide testing, and curriculum goals and objectives.

Overview of Design Tasks

The SLED Partnership has generated an array of standards-, engineering design-based tasks for grades three through six. These tasks range from one day activities designed to introduce students to the engineering design process to multi-day tasks that incorporate both science and mathematics conceptual understandings guided by the design process. What follows is a description of these tasks and their relevancy to the study presented here.

Design tasks used to introduce the engineering design process. Careful Carrier, Candy Bag, UV beads, and Coin Sorter were design tasks implemented at the beginning of the school year to introduce students to the engineering design process. Both Olive and Cecelia used introductory tasks as an opportunity for students to learn design-based terminology such as client, constraints, and problem.

Design tasks used to teach science concepts. Roller Coaster, Solar Tracker, and Wolf/Reindeer Habitat had associated science concepts that were the focus of implementation. Conceptual understandings of kinetic and potential energy, direct and indirect sunlight , and biotic and abiotic factors in biomes were applied, reinforced, or introduced through the use of each of these tasks, respectively. Although both Olive and Cecelia implemented these three tasks, Olive made a major modification to the original SLED-designed Reindeer Habitat. She replaced the reindeer with wolves as the context for designing a zoo habitat for animals. This change aligned more with the complementary curriculum and practices used with her humanities teaching partner.

Study Participants—The Cases

Olive. Olive was an enthusiastic and highly experienced sixth grade STEM teacher at an urban, Midwestern intermediate school. She had over twenty years of experience teaching science, mathematics, and language arts. At the time of the study, she was teaching science and mathematics and worked closely with a colleague who taught language arts and social studies to the same group of students. These teachers often organized class field trips and worked collaboratively to implement integrated curriculum. Olive also held a master's degree in education in addition to her bachelor's in elementary education.

Olive's experiences with design-based learning and teaching prior to participating in the study included leading a Sally Ride Toy Challenge team which was very successful. At the beginning of the study, she looked forward to "learning a lot about how to implement and improvements I need to make for the next time. So I have a lot to learn, I'm sure."

Cecelia. Cecelia was a grade 6-8 STEM teacher at a private, suburban Christian elementary school with four years of teaching experience. At the time of the study, she was teaching science and bible classes to sixth, seventh and eighth grade students. The focus of this study was her sixth grade science classroom. Cecelia held a bachelor's degree in elementary education with concentrations in science and math.

In general, Cecelia implemented design tasks to prepare them for using the engineering process in her classroom. Outside of implementation, Cecelia was eager to share her experiences with the design process through dissemination opportunities such as publishing in a practitioner journal and presenting at conferences. She looked forward to participating in the SLED partnership by "finding out what works and what doesn't work for the students."

Methodology

A comparative case study approach was used to characterize science teachers' orientations toward science teaching through engineering design. Data were collected over two years from Olive and Cecelia and then analyzed to produce two individual cases and one comparative case.

Data Collection

Data were collected over two years in the form of implementation plans, semi-structured interviews, classroom observations, pre- and post-observation interviews, and written reflections. A diverse set of data were collected allowing the researchers to see various aspects of the way participants reflected upon, planned for and implemented engineering design-based curriculum. Table 2 illustrates the data collected from each participating teacher.

Implementation plans were collected during the partnership's two-week summer institute. Grade 5 and 6 teachers collaborated with university faculty to compose multi-day, engineering design-based unit plans for implementing in the coming academic year. Each participant completed a total of four implementation plans.

Semi-structured interviews were conducted before and after the teachers' first year of implementation. These interviews encouraged the teachers to reflect on their goals for implementing design, their conceptions of the engineering design process, and their anticipated and experienced challenges. Two semi-structured, pre- and post-academic year interviews were conducted with Olive and Cecelia.

Classroom observations of the teachers' design task implementation were conducted in each participant's sixth grade science classroom. Observations lasted 5-7 days and field notes were recorded documenting the teacher's instruction. A total of five observations were conducted for each participant. In the second year of the study, the teachers participated in pre- and post-observation interviews. Pre-observation interviews focused on the teacher goals and plans for design tasks while post-observation interviews encouraged the teacher to reflect on how they met their goals and the impact of implementation on their views of science teaching through engineering design. Each teacher participated in a total of six pre- and post-observation interviews regarding their implementation. An example of a post-observation interview protocol is provided in the Appendix.

Written reflections were submitted electronically before and during the teachers' first year of implementation. The participants reflected on a design task of their choice and described their students' performance and how they could improve their integration of engineering design in their classrooms. Each teacher submitted a total of two reflections.

Table 2.

Data sources for each participant

Data Source	Description of source	Olive	Cecelia
Implementation Plans	Multi-day design-based lesson plans	4	4
Semi-structured Interviews	Pre-post academic year	2	2
Classroom observations	Multi-day observation of design task implementation	5	5
Pre/Post Observation Interviews	Conducted before and after classroom observation	6	6
Written Reflections	Based on one task and uploaded to online database	2	2

Data Analysis

The data for this study were analyzed using a comparative case study approach (Patton, 2002). Each participant's set of data was compiled and organized chronologically into a case record used for analysis (Patton, 2002). The data were analyzed first as two single cases before conducting a cross-case analysis of both participants (Patton, 2002). It was important to pay special attention to the participants individually first as the "credibility of the overall findings will depend on the quality of the individual cases" (Patton, 2002, p. 450). In other words, a descriptive and rich individual case provided the foundation for a credible cross-case analysis and discussion.

Analysis of the individual cases was focused primarily on the general views, practices, assessments, goals, and influences of the teacher in order to reveal the teachers' orientations. The purpose of analyzing these aspects of the teacher's instruction was to provide information about: (a) what the teacher hoped to accomplish through science teaching using engineering design (i.e. the teacher's goals), (b) the practices, assessments, and instructional strategies the teacher employs in her attempts at reaching her goals, and (c) the teacher's specific views, beliefs, and purposes influencing her teaching knowledge and decision making within a design-based context. As the data were analyzed, several "filters" for the teacher's instructional decisions were revealed. Across each of these domains of the teacher's instruction, recurring filters emerged which were categorized and named as the teachers' orientations. These orientations are described in the results of the individual cases.

Cross-case analysis focused on elucidating how the teachers' purposes for their instructional decisions diverged. For example, both teachers chose to use direct instruction to teach science concepts before implementing a design task. However, their purposes for frontloading the science were unique and revealed divergent orientations from similar practices. These subtle nuances were explicated and discussed in the final stage of analysis.

Results

The results of the individual case analysis and the comparative case analysis are presented below. Individual case analysis revealed two science teaching through engineering design orientations for Olive and Cecelia. Olive's orientations included the following: (a) career-readiness in science and engineering and (b) integrated curriculum. Cecelia's orientations included the following: (a) solid depth of scientific understanding and (b) teacher as a professional science educator. A comparative case analysis revealed two comparable features of instruction: (a) The placement of engineering design tasks as culminating activities and (b) An emphasis on student collaboration. The teacher's respective orientations and comparable classroom features are outlined below.

Olive's Orientations

Career-readiness in science and engineering orientation. Olive's first orientation is described as a career-readiness orientation. Within this orientation, Olive used authentic examples of how engineers and scientists work together, make careful notes, and share ideas in order to inspire students to emulate the skills of the respective professionals. Olive believed that the purpose of science teaching and learning was to enable students to practice the skills and use the tools of a scientist or engineer. By making it apparent to her students that science concepts are not isolated to a science classroom but are authentically utilized by scientists and engineers, Olive hoped to make her instruction more meaningful to her students and prepare them for entering those fields.

Specifically, her class defined the engineering design process as a "method engineers use to design prototypes." This definition of the design process from the perspective of an engineer was often reinforced with real-life examples generated during class discussions. Improving the performance of Lance Armstrong's bicycle and designing airplane wings for the United States Air Force were two scenarios Olive discussed with her students in an effort to help them identify with the usefulness of the design process.

Olive's assessments of student performance on an engineering design task within her career-readiness orientation focused on having students stay organized and complete accurate and detailed design sketches including itemized lists of materials in their design notebooks. Her purposes for evaluating the notebook entries were for students to demonstrate clear sketching and note booking skills and to document their learning of scientific and engineering practices. Olive considered this form of documentation to be an important practice of scientists and engineers because it validated their work and allowed them to share their science conceptions and design ideas with evidence and clarity.

Integrated curriculum orientation. Olive's integrated curriculum orientation was based on her attempts to make connections, not only between her science classroom and authentic science and engineering scenarios, but also between science, mathematics, engineering and language arts concepts, and real-world applications. This orientation was Olive's driving force for collaborating closely with her humanities teaching partner, taking students on field trips, inviting guest speakers, encouraging students to share real-life connections, and showing news and video clips with relevant and thought provoking ideas. Within this orientation, Olive's purpose for welcoming relatable experiences and linking science concepts to other disciplines was to make students' understandings more sustainable and meaningful.

Olive's passion for the interconnectedness of science with other disciplines was largely a product of one previous three-year professional development experience which Olive described as the most valuable and "paradigm-shifting" learning experience in her teaching career. This experience focused on conducting scientific research in a laboratory where teachers learned how to make connections between science content, authentic experiences, and other subject areas. Olive's learned appreciation for meaningful connections was evident in her reflection on her own experiences as a science student: "I was just taught science concepts and sometimes the whole thing didn't come back together." Olive's desire to present her science curriculum in a relatable manner within this orientation was an attempt to eradicate these traditional teaching methods that focused on isolated facts and concepts.

Olive's most successful and comprehensive integration of disciplines was a year-long interdisciplinary project focused on wolves. Olive's class worked with her humanities colleague and researched wolves, read a novel about a wolf pack, travelled to a local wolf park, and adopted one of the wolves at the park. By the end of the semester, students were well- prepared to design a wolf habitat using the engineering design process. The students practiced reading comprehension and creative writing, learned about biomes, biotic and abiotic factors, and applied math concepts to calculate amount of surface area necessary for natural resources in their designs.

Cecelia's Orientations

Solid depth of understanding orientation. Cecelia's first orientation is based on her frequent discussion about the ways that her students' science knowledge was solidified through the use of engineering design, making abstract science concepts more concrete. Within this orientation, Cecelia believed that the role of engineering design tasks was to help students deepen their understandings of science concepts.

Cecelia described her preferred instructional strategy as a three-step approach to science teaching. She would begin a lesson with an engaging activity that got the students' "wheels spinning," followed by more direct instruction regarding science concepts and vocabulary, and ending with a hands-on way to apply or use what they learned in order to "really nail down concepts." For example, Cecelia implemented a Morse code toy design challenge which began with an open-ended circuit activity. She then used direct instruction to introduce students to circuitry vocabulary (e.g. insulators, conductors). Finally Cecelia gave her students the challenge of designing a toy that used Morse code to light a bulb. According to Cecelia, using this lesson structure allowed her students "… to put everything together to make it work…make them explore…and then let them apply those to different situations."

In addition to her systematic three-step approach, Cecelia also used daily pedagogical strategies in class discussions and assessments in an attempt to solidify her students' conceptual understandings of science concepts. For example, she enjoyed being able to use examples generated from design-based experiences to help her students make connections to key science concepts they were learning at the time. During her implementation of design tasks, she redirected her students to these science concepts by asking questions such as, "What would be some helpful concepts to remember as we build a device to track the sun?" and "Remember when we did the reindeer habitats and the reindeer needed this much water? Well, what happens if we had half that much water? What happens if half the water was polluted from human influences?" In other words, engineering design tasks provided Cecelia with the platform she needed to "extend" science concepts "by continuing to refer back to it." According to Cecelia, her students would harbor fewer misconceptions after completing a design task because the tangible artifacts produced in the design process would help them "understand the [academic] standards at a deeper level."

Teacher as a professional educator orientation. Cecelia's professional educator orientation is based on her high regard for teaching as a profession and its influence on her goals and practices as a science teacher. Her purposes for implementing engineering design-based activities were two-fold. Cecelia wanted to contribute to the research on implementing engineering design in the K-12 classroom. She also wanted to learn more about how design-based methods are successful in science teaching and learning. Hence, Cecelia's intentions for using engineering design in her classroom were focused on the direct impacts that reform-based practices could have on her science classroom and the partnership at large. Cecelia believed that incorporating engineering design tasks helped support her goals as a science educator.

Cecelia attempted to use the engineering design process to positively impact the implementation of her science curriculum. This was evident in her goal for her students to effectively use engineering practices in order to improve subsequent implementations of engineering design tasks. In other words, the more her students engaged in the engineering design process, the better her students became at "independently participating in design-based activities." As her students learned to "confidently engage" in engineering design practices—team collaboration, identifying the design problem, planning a solution with effective use of materials—Cecelia hoped to see smoother, less challenging implementation of design tasks in her classroom as the year progressed.

Finally, Cecelia sought to make impacts on the partnership. She joined the partnership in an effort to learn more about "how engineering design would work in her classroom" and to contribute to the partnership's knowledge of design-based practices and implementation. She saw her participation as a truly symbiotic relationship between herself and the researchers. In return for the curricular resources and support, Cecelia worked hard to disseminate her findings and experiences. Her dissemination efforts included attending and presenting at teacher organization conferences and writing an article for a practitioner's journal. In this way, Cecelia hoped to contribute to the science educator profession by implementing reform-based practices and working with teacher educators to make their efforts more effective.

Comparative Cases: Olive and Cecelia

The aim of comparing the teachers' orientations was to differentiate the various purposes of making certain instructional choices in their implementation of engineering design-based tasks in their science classrooms. In some instances, Olive and Cecelia set the same goals and made similar curricular decisions. However, their purposes for their instruction were essentially different. These divergent purposes and their influence on the implementation of engineering design are discussed below. Figure 2 illustrates that Olive and Cecelia's similar classroom features were a product of their respective orientations toward science teaching through engineering design.

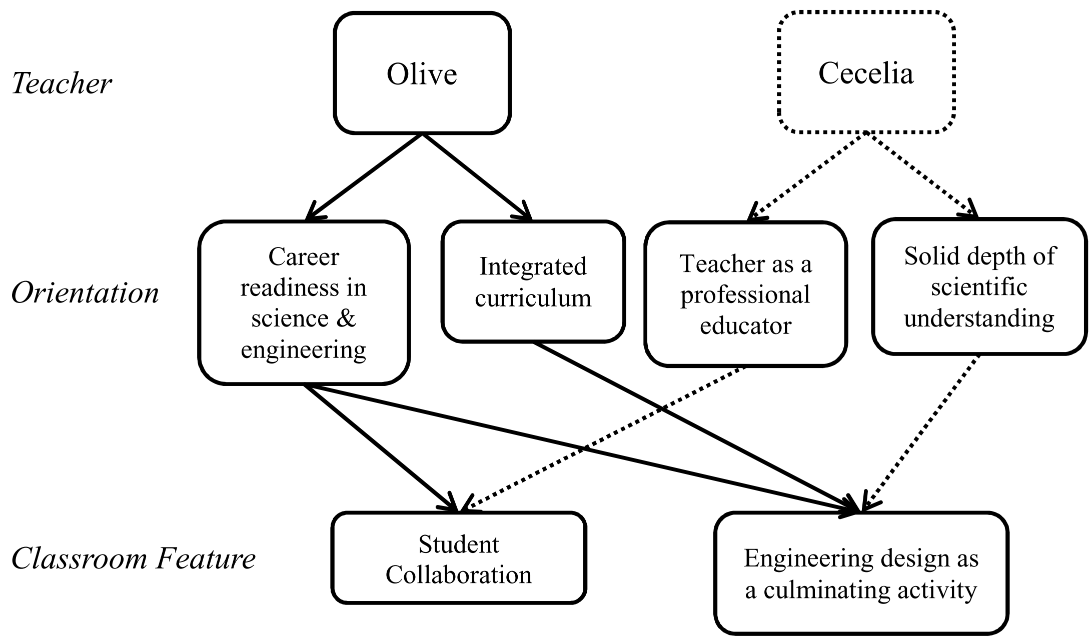

Figure 3. Olive and Cecelia's orientations and their relationships to classroom features

Use of engineering design tasks: Where do they fit and why? Both Olive and Cecelia chose to use direct instruction or guided inquiry activities to teach science concepts before having their students engage in engineering design tasks. The teachers' utilized similar instructional strategies before a design task to teach science concepts including the use of videos, online simulations, experiments, note-taking, and whole-class discussions. However, each teacher's purposes for frontloading the science learning and then using an engineering design task as a culminating activity were unique. Olive and

Cecelia's contrasting reasons for using comparable teaching methods are described below.

Olive viewed science and engineering practices as separate and distinct from one another. Furthermore, Olive did not believe science can or should be constructed through the use of engineering design. Instead, her purpose for using engineering design was to emulate what "engineers do in the real world" thereby extending science concepts to a "real-life situation." Olive also believed that the purpose of science teaching was to encourage students to "try to make sense out of their world because that's what scientists do." Olive's perspective of the complex relationship between engineering and science practices was that engaging in an engineering design task was "useless without the science behind it." Thus, Olive's orientations which highlighted the authenticity and interconnectedness of engineering and science resulted in her purposeful sequencing of learning activities.

Cecelia, on the other hand, used engineering design as a means of making abstract science concepts more concrete for the students. Therefore, from her perspective, Cecelia believed her students needed background science knowledge before engaging in a design task. Cecelia did not place as much emphasis on scientific inquiry as a learning process for making sense of science concepts as Olive did. Instead, according to Cecelia's *s*olid depth of understanding orientation, Cecelia used traditional instructional methods to introduce science concepts and then incorporate either an inquiry activity or an engineering design task to deepen the students' science conceptual understandings. This was evident in Cecelia's three-step approach to science instruction, wherein she preferred engineering design to inquiry activities in the last phase of learning. According to Cecelia, engineering design tasks were highly effective for “implanting [science] concepts. Otherwise, the students might do well on a test and then not think about it again until the next test or the next grade. These are tasks that I think by doing it and making it, they’ll really remember and understand deeper the concepts underneath.”

In summary, Olive and Cecelia placed engineering design tasks in their curriculum as culminating activities. This means their students first constructed science conceptual understandings through inquiry or traditional methods before applying their knowledge to a design-based problem. However, each teacher’s science teaching through engineering design orientations revealed divergent reasons for sequencing their instruction in similar ways. Olive believed that students *construct* scientific conceptual understandings by using science practices while students *connect* science concepts through engineering practices. In contrast, Cecelia believed inquiry and engineering design could be interchanged and were useful for enhancing students’ science understandings but that design tasks were seen as the more effective of the two at rooting students’ abstract conceptions to concrete experiences.

Working in engineering teams: why is collaboration important? A goal for both Olive and Cecelia was for their students to learn to work collaboratively. Interestingly, this goal had different purposes for each teacher. Olive’s goals for teamwork were a product of her career readiness in science and engineering orientation. Cecelia’s desire for students to work collaboratively was driven by her teacher as a professional educator orientation.

Student collaboration was a key element in Olive’s career readiness orientation. Working together in design teams was an engineering design process skill that Olive hoped her students would imitate from the work of engineers and scientists. Team collaboration and the accompanying skills—communication, listening, sharing equitably, negotiating a plan—were an integral part of emulating the authentic work of engineers and scientists. One of Olive's goals within this orientation was to help her students develop a positive attitude for working in teams. She focused on fostering teamwork because she believed her students' collaborative experiences allowed them to "gain confidence in their work" which in turn, increased the "quality of their work." She often related her students' abilities to work in teams to the synergetic work atmosphere of engineers. For example, to introduce her students to the team design phase of an engineering design task, she described the students' behavior in an engineering classroom at a local university: "They are all around tables, working together as a team." She considered team work a life and career skill that her students needed to develop to help ensure that the team's needs and goals were met in an engineering design task. By becoming team players — sharing ideas, negotiating a design plan, critically reflecting on design performance — Olive's students would take ownership of their work and see themselves capable of working together much like engineers or scientists.

Within Cecelia's teacher as a professional educator orientation, she hoped her students would learn how to work cooperatively in teams in order for subsequent implementations of design tasks to go smoothly. According to Cecelia, if she successfully encouraged her students to adopt harmonious methods of teamwork, it would positively impact her implementation of engineering design tasks. According to Cecelia, listening to one other and discussing design changes as a team "led to good decisions" in their choice of materials and design of the prototypes. Therefore, in any other design-based activities she chose to implement throughout the year, her students would be able to work confidently through the design process. Specifically, Cecelia looked for indicators that design-based practices were being used effectively in her students' ability to "work together" and "collaborate in their learning [to] understand the concepts." For this reason, collaboration was a signature element of Cecelia's teacher as a professional educator orientation to teaching science through design.

Discussion

In the following discussion, Olive and Cecelia's orientations toward science teaching through engineering design are discussed within three contexts: (a) science teaching orientations previously found in the literature, (b) alignment with the tenets of integrating science and engineering in the *Next Generation of Science Standards* (NGSS Lead States, 2013a), and (c) influences from prior science teacher development experiences. Olive is described as having a practical perspective whereby she attempted to influence her students' learning of science and engineering outside of her science classroom and in more authentic, real world contexts. In contrast, Cecelia held a professional perspective such that she wanted her students to use engineering design to improve her own science teaching practice and her students' learning.

Olive's Practical Perspective

Olive's career-readiness orientation complements Greenwood's (2003) "utilitarian conception of science" (p. 229). Results from this study suggested that the teacher participant embraced a science-technology-society (S-T-S) view of science curricula (strongly influenced by his previous career as an engineer) where the applications of science to technology in a societal context were prevalent (Greenwood, 2003).

Furthermore, Olive's integrated curriculum orientation relates also to "interaction of science, technology and society," a purpose for teaching science found in teachers who attempted to "link the subject (science) to life…something they see every day, maybe something that people use at work or a job" (Dani, 2009, p. 294). Olive 's orientations allowed her to help students focus on the idea that science knowledge is constructed through inquiry and then applied to engineering design through the improvement of technology in various, connected contexts and disciplines. Her utilitarian view of engineering design followed closely with the suggested focus of engineering in the K-12 classroom according to current reform documents.

Although neither teacher participant in this study chose to have students construct scientific understandings through engineering design tasks (Fortus et al., 2004, 2005), their uses for design-based practices remain significant. For example, Olive's focus on the work of scientists and engineers within her career readiness in science and engineering orientation aligns closely with aim of emphasizing science and engineering practices in *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012). Within this reform document, it is proposed that when students engage in the practices of science, it gives students "an appreciation of the wide range of approaches that are used to investigate, model, and explain the world" (NRC, 2012). The results of this study suggest Olive successfully incorporated the engineering design process into her practice because "the best science education seems to be one based on integrating rigorous content with the practices that scientist and engineers routinely use in their work" (NGSS Lead States, 2013b, p.11)"which she frequently accomplished as a result of her orientations. Here, Olive's professional development experiences are used to explain her reform-minded orientations.

According to Adamson et al. (2003), "teachers tend to align their pedagogical and curriculum decisions with how they themselves were taught" (as cited in Campbell, et al., 2013, p. 2039). Interestingly, Olive leveraged this tendency as a driving force for improving her teaching and rejecting traditional (i.e. didactic) methods of teaching science. For this reason, she valued professional development and years of teaching experience to continue to improve student learning in and outside her classroom.

Greenwood (2003) found that teachers' conceptions of science, personal PCK, and teaching experiences had a large influence on teacher's orientations. Olive's "paradigm-shifting" experience with inquiry-based professional development (PD) and subsequently her participation in the SLED partnership helped her build a strong framework of knowledge for teaching science through inquiry and design. This knowledge allowed her to position inquiry and engineering design along side of one another much like they are discussed in the *NGSS* (NGSS Lead States, 2013a; 2013b). In fact, Olive's understanding of and respect for inquiry-based science was so rich as a result of PD that she expressed concern that inquiry would not be addressed in the SLED summer institute and was relieved this was not the case. In her words, "science isn't based on engineering design; science is based on inquiry. I would hope that when I go into someone's room, they wouldn't just be doing engineering design, but would also focus on scientific inquiry." In her classroom, Olive viewed scientific inquiry as a process scientists use to construct scientific understandings; engineering design is a "process engineers use to improve our lives" by applying science understandings to a design solution. In this way, both science and engineering practices were equally important and supportive of each other in Olive's instruction.

Cecelia's Professional Perspective

Cecelia's science teaching through engineering design orientations acted as filters for her instructional choices which allowed her students to develop deeper understandings of science concepts and which positively enhanced her own science classroom and the research efforts of the partnership. With Cecelia's attempts to imbed design into her preferred inquiry-based lesson structure, she perceived the purpose of engineering design to loosely "mirror" inquiry learning much like a science teacher believed problem-based learning (PBL) mirrored inquiry (Rogers et al., 2011). More specifically, Cecelia utilized scientific inquiry and the engineering design process to serve the same purpose: enhance and deepen the students' understanding of science concepts. According to Cecelia, however, engineering practices "work the best…even better than other things that we [science teachers] do" to help students apply and comprehend abstract science concepts on a concrete level.

Cecelia's goal of developing deeper conceptual understanding of science through engineering design is highly reform-minded. For example, her solid depth of understanding orientation complements the idea that engaging in both engineering and science practices makes the students' "knowledge more meaningful and embeds it more deeply in their worldview" (NRC, 2012). Furthermore, the presence of engineering helps to extend and solidify "their understanding of science by applying their developing scientific knowledge to the solution of practical problems" (NGSS, Lead States,

Appendix A, p. 3). Again, Cecelia's reform-minded orientations are explained through her teacher development experiences.

Factors which may influence a teacher's ability to utilize their available PCK include but are not limited to the "complexity of teachers' knowledge structures and the extent of teachers' practical experience" (Morine-Dershimer & Kent, 1999, p. 26). Thus, more novice teachers may have weaker orientations adopted from preservice course work that act as "gate-keepers for the acceptance or rejection of teaching material" (Gess-Newsome, 1999, p. 78). Cecelia had less than five years of teaching experience and SLED was the first major professional development experience she participated in. While she was an eager learner and sought to contribute to current reform efforts, her background knowledge about inquiry-based practices was not developed enough through classroom experience to encourage her to sustainably integrate both science and engineering practices in her instruction as Olive did. Instead, Cecelia preferred to draw from her preservice course work in science teaching methods to structure her curriculum units using a three-phase learning cycle (elicitation, development and application) to integrate engineering design, sometimes at the expense of inquiry (Lawson, 1995 as cited in Abraham, 1997).

To briefly explain, the elicitation phase, also called exploration, drew students in with an interesting question or investigation. The development phase, also called conceptual invention, allowed students to learn the concepts revealed through exploration. Finally, the application phase was used to extend or reinforce the concepts labelled in the development phase (Abraham, 1997). Prior to Cecelia's participation in the SLED institute, she typically used inquiry-based experiments or activities in the final "application" phase. During her design-based experiences, she sought to improve her implementation of the learning cycle by frequently replacing inquiry lessons with engineering design tasks. From her perspective, Cecelia believed design tasks were more engaging and beneficial to students because they helped them "understand the concepts at a deeper level" than inquiry did.

Conclusions

Results of this comparative case study revealed differing intentions for implementing engineering design into the science classroom that resulted in various methods of instruction. Two orientations toward science teaching through engineering design were found for each teacher participant from individual case study analysis. Olive's orientations included (a) career readiness in science and engineering and (b) integrated curriculum. Cecelia's orientations included (a) solid depth of scientific understanding and (b) teacher as a professional science educator. In comparative case study analysis, it was revealed that teachers in this study who implemented engineering design into their classrooms used similar instructional strategies or set comparable goals for instruction, yet the teachers demonstrated differences in their purposes, or intentions, for making these pedagogical decisions. Furthermore, the teachers' respective orientations were found to align in some ways with current reform efforts and were developed largely from their knowledge and experiences gained from teacher education.

The heavy influence that knowledge and experience played in Olive and Cecelia's orientations to science teaching through engineering design indicates that teacher educators and science education researchers can learn important information from case studies such as these. In other words, Olive and Cecelia used diverse design-based instructional practices manifested in unique ways based on their respective orientations. This allows for a proposal of knowledge domains that deserve special attention in current reform efforts:

- A clear and distinct understanding of the unique differences between engineering and scientific practices and processes in the science classroom (i.e. what does it mean to engage in scientific inquiry? What does it look like when students use science concepts to solve an engineering problem?)
- The various purposes for implementing engineering design in the science classroom (e.g. application of science concepts, emulating the work of engineers, etc.) and how those purposes may or may not align with the nature of the *NGSS.*

Teacher educators and science educator researchers should be made aware of these components of knowledge which, when learned, may help teachers to effectively integrate science and engineering practices in their classrooms

Implications

The results of this study have implications for teacher development regarding the implementation of engineering design in the K-12 science classroom More specifically, implications of this study suggest that preservice and inservice teachers require specialized professional development and practical experiences to shift their teaching practices to better fit the integration of science and engineering practices outlined in reform documents.

First, because the participants' knowledge and orientations were enhanced from classroom experience, preservice teacher preparation may benefit from implementing practical field experiences with engineering design-based curriculum earlier in the program and more frequently. Secondly, science methods courses should allocate ample time and opportunities for preservice teachers to develop their knowledge about inquiry and engineering design separately before making attempts to integrate the two into instruction.

Inservice professional development efforts may also learn from this comparative case study. For example, professional developers should elucidate teachers' past experiences, views, and knowledge to help them leverage their teaching transformations. According to Gess-Newsome (1999), orientations "are individually held and idiosyncratically developed" thereby making "any strategy less labor-intensive than conceptual change approaches" less effective in sustaining reform changes (p. 88). That is, in order for teachers to make transformations in their classroom, they need to be aware of and target their views and knowledge that may be hindering reform.

Further implications from this study suggest taking a closer look at the design of professional development (PD) programs as well. Some research has extended the construct of orientations to characterize the goals and practices of professional developers and their programs' design and implementation (Musikal & Abell, 2009 as cited in Rogers, Abell, Marra, Arbaugh, Hutchins & Cole, 2010; Marra, Arbaugh, Lannin, Abell, Ehlert, Smith, Merle-Johnson, Rogers, 2011). These orientations to professional development were shown to provide guidance in developing PD by facilitating concerted decision making within PD teams and leading to positive implementation outcomes. For this reason, it is important to reflect on the characteristics of PD that are effectively transforming teacher practice.

Alongside suggestions for teacher education, further research is proposed regarding teachers' implementation of engineering design in science classrooms and the development of science teaching orientations. The following research questions summarize the focus of suggested further investigations:

1. How do teachers' subject matter knowledge, pedagogical knowledge, and contextual knowledge influence their orientations and, as a result, their instructional decisions when integrating engineering design?
2. How do teachers' conceptions and knowledge about science and engineering practices and processes support their orientations to science teaching through engineering design?
3. What are the orientations of professional development programs attempting to enhance teachers' implementation of engineering design in the K-12 science classroom?
4. What are the relationships between orientations to professional development and participating teachers' orientations to teaching science through engineering design?

In summary, results of this study suggest that more knowledge can be gained from examining how orientations may interact with the other components of teacher knowledge, how teachers' knowledge about science and engineering practices affects their instructional decisions, and how orientations to professional development may influence the orientations of science teachers attempting to transform their practice.

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Appendix

Post-observation Interview Protocol

Part 1: The purpose of the questions in part 1 is to determine the types of pedagogical strategies the teacher usually prefers to use to teach the science unit and to compare and contrast these strategies to those used in the design task.

1. *What would you say are your favorite strategies to use when teaching this unit? Why?*
2. *How does [design task] support your goals for student learning? For your instruction?*
3. *If you were not teaching using [design task], what strategies or materials would you use to teach these concepts instead? (Hynes, 2012)*

Part 2: The purpose of part 2 is to examine the teachers' goals for student learning and assessment.

4. *What would you say was most important for your students to learn from [design task]? (Hynes, 2012)*
5. *As a teacher, how can you best help students learn (concepts, skills, or practices) in this unit? (Friedrichsen, 2002)*
6. *How did you assess the students' learning in this unit? Why was this assessment used? (Friedrichsen, 2002)*

Part 3: The purpose of part 3 is to reflect on the instructional practices the researcher observed during the observation and look at the purposes and goals behind those practices. These questions are generated during and after an observation and should be prepared from field notes before the interview (Hynes, 2012). For example:

7. *You decided not to test the students' solar trackers and had a whole-class discussion about their designs instead. How did this modification support your goals for science instruction?*