The Development of In-Service Science Teachers' Pedagogical Content Knowledge

Related to Interdisciplinary Science Inquiry

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Abstract

This study was situated in a NSF-funded multi-year teacher professional development project, the Interdisciplinary Science and Engineering Partnership (ISEP), between the university and a school district in the North Eastern United States. The ISEP project affords an opportunity to understand the processes and conditions in which science teachers develop interdisciplinary science inquiry knowledge and how that is translated into their pedagogical content knowledge (PCK). As part of that study and within the framework of PCK in science, this study explored (1) the extent to which the involvement of in-service science teachers in authentic research experiences impacts their PCK of interdisciplinary science inquiry, and (2) the factors that contribute to or constrain the development of interdisciplinary science inquiry PCK. This research study utilized a mixed method, explanatory research design. Results showed that teachers participating in the ISEP project demonstrated various levels of change in regards to their PCK, understanding of ISI, and implementation of ISI in classroom practices. The core features of ISEP identified as impacting this change included (1) the summer research connection, (2) collaboration with STEM students, (3) an active learning environment, and (4) duration. The above findings have implications for planning and conducting effective in-service for science educators.

The desire for continuing improvements in science education spurred the development of the Next Generation Science Standards (NGSS), which were completed and released in the spring of 2013 (Achieve, Inc., 2013). While the call for inquiry-based teaching is not new to the world of science education (National Research Council [NRC], 1996, 2000), the NGSS expands scientific inquiry to developing science and engineering practices that are combined with disciplinary core ideas and crosscutting concepts. This new vision of science teaching and learning may be called interdisciplinary scientific inquiry. With this form of inquiry, while maintaining the distinctness of traditional disciplines, the lines between the branches of science, engineering, and technology are blurred as students are asked to solve meaningful, everyday problems.

> Interdisciplinary science inquiry (ISI) is a mode of inquiry that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice. (NAS, 2004)

The emphasis of ISI in the next generation science standards represents a bold conceptual shift on how science should be taught within schools in the United States in the future (NRC, 2012). In order for this new form of inquiry to be successfully implemented into classrooms, teachers must not only be knowledgeable about science and engineering, but also know how to relate science and engineering to the lives and needs of their students.

Developing science teachers' pedagogical content knowledge on ISI is necessary in order for teachers to implement ISI in their classrooms. Shulman (1986) originally defined PCK as "subject matter knowledge for teaching" and as "the ways of

representing and formulating a subject that make it comprehensible to others" (p.9). While there is still no universally accepted conceptualization of PCK (Abell, 2007; van Driel, Verloop, & de Vos, 1998), understanding what it entails, how it changes, and the factors involved in that process has the potential to lead to changes in science teachers' practice that can in turn improve student learning (Abell, 2007).

According to Loughran, Berry, and Mulhall (2012), "much of the research into PCK has demonstrated, it is a complex construct that, in many ways, is only fully recognized when seen through the cumulative effect of the way a teacher constructs and teaches a unit of work" (p. 10). Additionally, teacher change is a long-term process and one that does not occur overnight. Loughran et al. (2012) refers to the changes that occur in one's teaching as a journey, not an event.

> They did not teach one way at the start of their adventure and then suddenly transform their teaching overnight to become new and different teachers. They came to develop their teaching as they experimented with their practice and built new understandings of teacher and student learning. (Loughran, Berry, & Mulhall, 2012, p. 2)

Yet, in a review of research published between 1986 and 2010, Schneider and Plasman (2011) found very few longitudinal studies that followed teachers for more than one year. While this may be due in part to the constraints that researchers have with studying teacher, according to Abell (2007), when measuring complex avenues of teaching, such as PCK, studies that "use multiple methods over an extended period of time provide researchers with a rich set of data from which to draw conclusions and make inferences" (p. 1123). Loughran et al. (2012) identified that while much of the research on PCK can

be on how to evaluate it, one of the major gaps in today's research on PCK is how an understanding of PCK is directly correlated to enhancing science teaching practice (p. 11). This study will hopefully begin to fill that gap by not only describing the changes that occur in science teachers' PCK on ISI, but also explaining how those changes are resulted in the hope to develop a theory for improving science teachers' knowledge and practices on ISI.

The research questions that guided this study are:

1. To what extent and in what ways does the involvement of in-service science teachers in authentic interdisciplinary science inquiry experiences impact their PCK of interdisciplinary science inquiry?

2. What factors contribute to or constrain the development of in-service science teachers' development of interdisciplinary science inquiry PCK?

Theoretical Framework

The theoretical frameworks adopted by this study include Magnusson et al.'s (1999) model of PCK to understand teachers' interdisciplinary science inquiry PCK and its enactment in their classroom practices and Desimone's (2009) theoretical model of teacher professional development (PD) to understand how and why teachers' PCK on ISI change. Describing and understanding teachers' PCK in terms of their knowledge and implementation of aspects of ISI are a valuable and necessary first step in determining further courses of action that can be taken to promote implementation of ISI as a result of NGSS.

Magnusson et al.'s (1999) model of PCK served as the framework with which to understand how teachers understand interdisciplinary science inquiry and implement it in

their classroom practices. According to Magnusson et al. (1999), pedagogical content knowledge includes: (a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum, (c) knowledge and beliefs about students' understanding of specific science topics, (d) knowledge and beliefs about assessment in science, and (e) knowledge and beliefs about instructional strategies for teaching science. These five components of a teacher's PCK where framed within the concept of interdisciplinary science inquiry (ISI). Following the conceptions of integrated science (Fogarty, 1991; Klein, 1990, 1996; Petrie, 1996; Lederman & Niess, 1997; Lonning & DeFranco, 1997) and the conceptual framework for next generation science standards (NRC, 2013), the ISEP research team defines ISI to consist of four dimensions: (1) the purpose (i.e. drivers) of ISI; (2) science and engineering practices; (3) crosscutting concepts; and (4) disciplinary core ideas in life science, physical science, earth and space science, and engineering and technology. Understanding teachers' PCK in terms of their knowledge and implementation of aspects of ISI are a valuable and preliminary step in determining further courses of action that can be taken to promote further implementation of ISI.

Desimone's (2009) theoretical model of teacher professional development (PD) will also guide the design, data collection and analysis in this study. This model incorporates 2 key components: (1) recognizing the critical features used to define an effective model of professional development, and (2) an operational theory of how professional development influences teacher and student outcomes (p. 184). As such, it "represents interactive, nonrecursive relationships between *critical features* of professional development, teacher knowledge and beliefs, classroom practice, and student outcomes" (p. 184). Desimone (2009) defines critical features as the "characteristics of

an activity that make it effective for increasing teacher learning and changing practice"
(p. 183). Based on previous research in teacher professional development, Desimone
cites five characteristics of effective PD, which include: content focus, active learning,
coherence, duration, and collective participation. Utilizing Desimone's model for
studying professional development, the components of the ISEP teacher development
program will be examined to help identify the factors that contribute or constrain the
development of participating teachers' interdisciplinary science inquiry PCK.

Literature Review

In order to situate and to expand upon the PCK framework that guides this study,
this review explores research that has been done in developing the construct of PCK
within science education, the role that teacher beliefs and contextual factors play within
the transformation of one's PCK, as well as the impact that programs, similar to ISEP,
have had on teacher development.

Defining Interdisciplinary Science Inquiry

Much of today's research in science has become increasingly interdisciplinary, as
the demands that societal issues have placed on science can no longer be answered within
the realm of one distinct discipline (NRC, 2004). Drawing from the National Academics
Committee on Science, Engineering, and Public Policy report entitled "Facilitating
Interdisciplinary Research", interdisciplinary research is defined as

> A mode of research by teams or individuals that integrates information, data,
> techniques, tools perspectives, concepts, and/or theories from two or more
> disciplines or bodies of specialized knowledge to advance fundamental

understanding or to solve problems whose solutions are beyond the scope of a

single discipline or field of research practice. (p. 26)

The rationale that the authors of this report provided for why so much of today's research

is viewed and conducted through the lens of interdisciplinarity is based off of four drivers

or forms of motivation. These drivers include: the inherent complexity of nature and

society, the desire to explore problems and questions that are not defined to a single

discipline, the need to solve societal problems, and the power of new technologies. As it

is the case that the most fundamental, and often most interesting, questions and problems

regarding human society and nature are at their core complex; it can be surmised that the

answers to these questions and problems would in turn be complex requiring

collaboration across disciplines of science as well as the creation and use of advancing

technologies.

While there seems to be a consensus on the definition and nature of ISI in the

scientific community, the need to clarify what interdisciplinary inquiry means for science

educators, teachers and students in K-12 remains a challenge as most of science teaching

and learning, particularly at high school, is still disciplinary (Klein, 2000). Previous

efforts related to defining ISI for K-12 are in integrated science (Fogarty, 1991; Klein,

1990, 1996; Petrie, 1996; Lederman & Niess, 1997). Curriculum integration has been

defined as an approach, or teaching strategy, that purposefully compiles knowledge,

skills, and values from different subject areas to teach a concept in more meaningful way

(Wang, 2012). Many researchers distinguish in curriculum integration approaches as

multidisciplinary, intradisciplinary, interdisciplinary, and transdisciplinary (Drake, 1998,

Drake & Burns, 2004; Fogarty, 1991; Lederman & Niess, 1997; Lonning & DeFranco, 1997).

Following the conceptions of integrated science as a continuum and the conceptual framework for next generation science standards (NRC, 2013), the ISEP research team defines ISI to consist of four dimensions: (1) the purpose (i.e. drivers) of ISI; (2) science and engineering practices; (3) crosscutting concepts; and (4) disciplinary core ideas in life science, physical science, earth and space science, and engineering and technology.

Defining Pedagogical Content Knowledge for Science Teachers

Pedagogical knowledge is the "knowledge that is developed by teachers to help others learn" (Abell, 2007, p. 1106-7). Shulman (1986) originally defined PCK as "subject matter knowledge for teaching" and as "the ways of representing and formulating a subject that make it comprehensible to others" (p.9). He proposed several domains of knowledge that together influenced how teachers taught. Summarized by Hume and Berry (2011), Shulman's domains include: content knowledge; general pedagogical knowledge (i.e. knowledge of strategies for classroom management and organization); curriculum knowledge; pedagogical content knowledge; knowledge of learners and their characteristics; knowledge of context (i.e. classroom, school, and community); and knowledge the purposes and values of education. Since Shulman, the concept of PCK has been explored and expanded and the domains that contribute to a teacher's PCK have been further refined and defined (Hume & Berry, 2011).

From the original constructs of PCK devised by Shulman came additional models, such as the one conceptualized by Magnusson et al. (1999). Magnusson et al.'s model of PCK for science teaching consists of:

> (a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum, (c) knowledge and beliefs about students' understanding of specific science topics, (d) knowledge and beliefs about assessment in science, and (e) knowledge and beliefs about instructional strategies for teaching science. (p. 97)

"These components represent a broader view of PCK than the original conceptualization, which focused on topic-specific case knowledge, or what Hashweh (1985) called subject-matter pedagogical knowledge" (Abell, 2007, p. 1108).

Assessing and Measuring Pedagogical Content Knowledge

The complex nature of PCK as well as it's multiple definitions and constructs have resulted in the use and development of a large variety of methods by researchers to measure and assess PCK (Baxter & Lederman, 1999). These methods include: the lesson planning method developed by Volk & Brockman (1999); the use of metaphors; the use of "classroom window" cases developed by Loughran and colleagues; expert/novice studies; interviews; classroom observations; and teacher focus groups (Abell, 2007; Baxter & Lederman, 1999; Hume & Berry, 2011; Loughran et al., 2012). Baxter and Lederman (1999) organized these techniques, and others, for studying PCK into three categories: (1) convergent and inferential techniques, (2) concept mapping, card sorts, and pictorial representations, and (3) multi-method evaluations (p. 149).

Multi-method evaluation. Multiple method assessments of PCK, as its name suggests, utilizes a variety of techniques that allow researchers to triangulate their data

and from that infer a general profile of a teacher's PCK (Baxter & Lederman). For example, a study done by Hashweh used structured interviews, concept maps, and sorting of exam questions to assess teachers' content knowledge, conceptions of learning, instructional planning and view of instruction (Baxter & Lederman, 1999, p. 154).

Another example of a multi-method evaluation that has been developed and refined more recently is that of Loughran and his colleagues (2012). Expanding upon their original model for assessing science teachers' PCK though the "classroom window" scenarios, Loughran et al. (2012) developed a two-part PCK format that together can provide researchers with a more detailed understanding of a teacher's PCK. The two parts of the format are CoRe (Content Representation) and PaP-eRs (Pedagogical and Profession-experience Repertoires) that together form a Resource Folio. According Loughran et al. (2012), "a CoRe is a holistic overview of teachers' pedagogical content knowledge related to the teaching of a given topic and the associated PaP-eRs are narrative accounts designed to purposefully offer insights into specific instances of that PCK" (p. 20). Together the two form a Resource Folio, which is meant to be a more generalizable account of a teacher's PCK about a particular science concept. Studies using CoRe and PaP-eRs have found that they can be used to help teachers, particularly pre-service teachers, to develop more sophisticated and expert view about learning to teach science (Hume & Berry, 2011; Loughran et al., 2008, 2012)

PCK is a complicated construct that encompasses many aspects of a teacher's craft and as such is a construct that has yet to be fully developed (Schneider & Plasman, 2011). While gains have been made in making research in PCK more analytical and more clearly defined than early research in PCK, it remains a construct that is based on

researchers' ideas about professional knowledge. According to Schneider and Plasman (2011), what is necessary to continue the development of PCK is more empirical research in defining PCK in such a way that is it useful for understanding and enhancing teachers' knowledge. More specifically, future research needs to examine teachers' ideas about the specific components of PCK.

Research in each of Magnusson et al.'s (1999) 5 domains of PCK as well as that in developing tools to measure and assess PCK has shown that PCK has an impact on the type and quality of learning that takes place within today's science classrooms. While there is still no universally accepted conceptualization of PCK (Abell, 2007; Schneider, 2011; van Driel, Verloop, & de Vos, 1998), understanding what it entails, how it changes, and the factors involved in that process has the ability to lead to changes in science teachers' practice that can in turn improve student learning (Abell, 2007; Schneider & Plasman, 2011).

Impact of Research Experience for Teachers

One of the professed goals of the Interdisciplinary Science and Engineering Partnership (ISEP) is to improve middle and high school science teachers' knowledge and skills related to STEM areas of research through the engagement of these teachers in interdisciplinary science research and engineering design with university STEM faculty. The desired outcomes of this goal include that the participating science teachers will demonstrate advanced knowledge and skills in conducting scientific research and design, have an improved understanding of science and inquiry science teaching, and improved practice in conducting inquiry science teaching.

Both the goal and outcomes of the intervention mirror past research that has been done on the impact of providing science teachers with research experience (Dresdner & Worley, 2006; Lord & Peard, 1995; Pegg, Schmoock, & Gummer, 2010; Pop, Dixon, & Grove, 2010; Yerrick, Parke, & Nugent, 1997). For example, the NSF's Research Experiences for Teachers (RET) program provides teachers with the opportunity to develop and expand upon their real-world research strategies through the placement of those teachers in research laboratories. Based on the cognitive apprenticeship model, the RET program allows "teachers play the role of the student in the learning process in order to acquire the skills and knowledge relevant to the practice of science" (Pop et al., 2010, p. 129). The survey results of the study done by Pop et al. (2010) found that even though almost half of the teachers who participated in the RET program applied more real-life situations to their teaching activities and more than a quarter were more confident about teaching science, there was not an overall and immediate implementation of RET practices by the majority of participating teachers. These findings led the researchers to suggest that future research should focus not only on what the immersion programs offer in terms of laboratory and research experience for teachers, but what happens when teachers return to their classrooms.

Lord and Peard (1995) found that both science researchers and science education researchers have an impact on science teachers' attitudes towards science. In this particular study, science teachers in Philadelphia spent 3 weeks at a university where they spent time with practicing scientists in fields of physical, biological, and geological science during the day and then met with science educators in the evening to discuss pedagogical and practical applications of what they had learned during the day. Their

findings support the concept that in order for teachers to change, they must gain not only the skills of inquiry in the context of doing inquiry, but also the knowledge of how to integrate those skills within their classrooms and have the proper support system in place to facilitate the desired changes.

Contextual Factors

Contextual factors also play a role in influencing the actual practices of teachers. While teachers can learn new skills and teaching practices through the engagement in professional development programs, there are often factors within the school and classroom that impede their implementation of those skills and practices they have learned. According to Deci and Ryan (2000), "context affects learners in their choice of performing a certain task and the degree to which learners have control in this process" (cited in Pop et al., 2010, p. 130).

Teachers' beliefs regarding their knowledge, curriculum, and students' ability have been shown to influence their pedagogical decisions. In a study done by Gilbert and Yerrick (2001), the teacher's perception of how he viewed his students' ability to do science influenced how he taught science. The deficit lens with which he viewed his students severely limited the types of lessons he thought they would be able to successfully complete. As a result, his classroom practices were centered on learning basic scientific knowledge through the use of the textbook and "easy-to-follow directions and discrete packages of information relating to facts and proven theories included in the state-mandated earth science curriculum" (p. 585).

In a study that looked at how teachers' gained practical knowledge and skills related to inquiry-based curriculum implementation, Jones and Eick (2007) found that classroom

management and limited knowledge of how to confront students' preconceptions as obstacles to implementing inquiry. In this study, the researchers followed the two teachers highlighted through the process of implementing Science and Technology for Children (STC) and Science and Technology Concepts for Middle School (STC-MS). Their findings indicated that even though the teachers reacted positively towards the curriculum, there were several factors that have a negative impact during the implementation process. Those factors included the management of materials and time. Managing materials required to do inquiry in the classroom can lead to additional issues of classroom management for teachers, when compared to more traditional styles of teaching. In regards to time, planning for and implementing inquiry in the classroom takes more time than other forms of instruction and can lead to frustration. However, the researchers found that with additional use and support, the teachers in the study were able to more successfully implement aspects of the inquiry-based curriculum. These findings highlight the assumption that in order to better understand why teachers may or may not be implementing interdisciplinary science inquiry into their classroom practice, the contextual factors that get in the way of implementation need to be identified and addressed.

Urban School Context

In addition to the contextual factors identified previously, this study took place within an urban context, which is an important contextual factor to recognize and account for due to the challenges that urban schools face. Calabrese Barton (2001) in her critical ethnography on two young urban school children identified four distinct areas within urban science education where persistent inequalities exist: academic achievement,

resources, school practices, and the culture of schooling (p. 904). Poor academic achievement in urban schools is evident not only in standardized test scores (Anyon, 1997), but also in the significantly higher dropout rates of poor urban children and particularly poor, urban Black and Hispanic students (Fine, 1991).

Access to adequate and up-to-date resources that needed to effectively implement science instruction is another challenge faced by urban schools (Anderson, 2002; Johnson, 2006). According to Calabrese Barton (2001), resources include not only materials within the school, but also those within the community and home as well as human resources and school-based programs. Added to the limited access to resources is the culture of low expectations and low morale (Anderson, 2002; Johnson, 2006; Kozol, 2005).

Summary

PCK is a complicated construct that encompasses many aspects of a teacher's craft. As research in each of Magnusson et al.'s (1999) 5 domains of PCK have shown, PCK has an impact on the type and quality of learning that takes place within today's science classrooms. Additionally, changing a teacher's PCK is not a straightforward, step-by-step process. According to Loughran, Berry, and Mulhall (2012), changing a teacher's PCK can be thought of as "breaking set" (p. 5). Many teachers are set in a routine practice that is safe. When programs, such as ISEP, RET, or TIW, expose teachers to new ideas and practices, teachers must be able to break that set, which "can create unforeseen challenges as the teacher moves from a sense of confidence in, and knowledge of, particular practice to a riskier situation characterized by uncertainty and a heightened consciousness of learning about practice through a new situation" (p.5). In

order to support the process of "breaking set", researchers must look beyond just evaluating teachers PCK and develop an understanding of the many pieces and players involved in this process so that PCK can be used as a model to improve science teachers' practice.

Method

Research Design

The context of this study was a NSF-funded multi-year teacher professional development project between the university and a school district. The project began in the spring of 2012 with a pilot study and is currently finalizing the second year of full implementation. Beginning in the summer of 2012, teachers from the school district spent 4-6 weeks in the summer to conduct interdisciplinary research at the university research laboratories, industrial settings, or research institutions. After the summer research, they were expected to implement ISI in their classrooms during the academic year. These teachers also had the opportunity to take part in the ISI Professional Learning Community (PLC) pedagogical sessions during the academic year. These sessions afforded the participating teachers the opportunity to discuss and take part in activities that served to foster their development of ISI and the implementation of ISI strategies in their classrooms. About 60 to 70 teachers participated each year and many of them participated for multiple years. Other individuals involved in the partnership included university STEM faculty, science education faculty, undergraduate students and graduate students, and volunteer STEM professionals.

Participants and Site

The participants involved in the project included 73 in-service teachers who are currently teaching in a public middle or high school in a large city in the eastern United States. Table 1 provides additional information on the 12 participating schools.

<Insert Table 1 About Here>

During the second year (2012-2013) of the project, it was identified that the participating teachers fell along a spectrum of change and implementation. This spectrum ranged from limited knowledge and implementation of ISI to a significant knowledge of ISI and integrated use of the summer research experience in classroom practices. The 10 teachers selected this study were initially selected based on their PCK assessment score for pre-year 3. The teachers highlighted scored at the lower, middle, and higher end of the assessment and also illustrate the range of summer research experiences the project offers. To preserve the anonymity of the participants the names used are pseudonyms.

Data Collection

To truly understand the developing construct of a teacher's PCK in science and interdisciplinary science inquiry, the elements of PCK as identified by Magnusson et al. (1999) were evaluated through multiple methods. Qualitative data collection occurred during all three years of the project and included observations, interview, and the analysis of physical artifacts. Quantitative data was collected through a PCK assessment that the participating teachers completed during year 3 of the project.

Observations. A series of multiple observations took place throughout the three years of teacher involvement in the ISEP project. During these observations, descriptive field notes were taken. The types of observations included: (1) observations of the

teachers during their different summer experiences, (2) classroom observations during the pilot study and years 2 and 3, and (3) monthly pedagogical sessions held by the research team. A classroom observation protocol was established for the 2013-2014 school year and was composed of three parts: a pre-observation written interview that is adapted from CoRe: Content Representation Tool (Loughran, Mulhall, & Berry, 2012); a field observation form that is adapted from Reformed Teaching Observation Protocol (RTOP) (Sawada *&* Piburn, 2000*);* and a post-observation rating form that includes components of the ISI summer weekly log sheet and the Inquiry into Science Instruction Observation Protocol (ISIOP) (Minner & DeLisi, 2012).

Interviews. Semi-structured interviews were conducted with the participating teachers in years 2 and 3. Each year the interviews took place at the during the first half of the academic year. The structure of the interviews were premised on the following: (1) personal perception of the research experience; (2) proposed or actual plan for implementing research; (3) the types of activities or strategies they feel would be best used in implementing ISI; (3) knowledge of students' interest in the topic of study and their (i.e. students) ability to be involved in inquiry-based activities, and how that impacts the design or structure of lesson or unit planned; and (4) what foreseeable challenges do they anticipate or are encountering in implementing ISI in their classrooms.

Physical artifacts. Physical artifacts were collected throughout the course of the study. The artifacts collected included: (1) research proposals, (2) summer log sheets that teachers used to document their summer experiences, (3) research posters that teachers created at the end of the summer research experience, (4) implementation plans that

teachers developed, and (5) teachers' lesson plan, handouts or worksheets given to students, and copies of student work from classroom observations.

PCK assessment. The PCK assessment is a quantitative assessment tool that is being developed by the research team and was piloted in spring 2013. This assessment tool consists of 2 components: a standardized PCK assessment of the teacher's knowledge of their practice and subject matter and an assessment of ISI, both knowledge and practice. The content knowledge assessments covered chemistry, biology, earth science, physics, middle school science, and elementary school science. These assessments were developed by Assessing the Impact of the MSPs: K-8 Science (AIM) project and Assessing Teacher Learning About Science Teaching (ATLAST) project at Horizon Research, Inc. The middle and elementary school science assessment consisted of items from POSTT "Thinking About Science Teaching" (Schuster & Cobern, n.d.).

Data Analysis

The qualitative data was analyzed utilizing the framework of grounded theory. Through a constant comparative method, the multiple sources of data were analyzed to try and identify patterns of action and interaction (Strauss & Corbin, 1998). Data analysis activities began once the participating teachers completed their summer research experience and through the analysis of the summer research observations and initial interview, a framework for the teachers' perceptions towards ISI and how it could be implemented was generated.

The PCK scores obtained through the quantitative PCK assessment were analyzed using descriptive statistical analysis. The initial scores were used to identify which

teachers would be highlighted in the study. Teachers were selected based on whether their score fell below the mean, at the mean, and above the mean. (See Table 2)

<center><Insert Table 2 About Here.></center>

Of the 69 teachers who completed the assessment, 24 were initially selected. The number selected from each assessment group was based on the total number of teachers who took that particular assessment. The observation, interview, and physical artifact data was then compiled for each teacher for that teacher's entire involvement in the project, which ranged from one to three years. Based on the fidelity of the data that was compiled for each of the 24 teachers, on the initial PCK scores, and on the type of summer research experience(s), a sample of 10 teachers were selected.

All interviews and observational data were audio-recorded, transcribed, and coded using HyperResearch qualitative software. The interview transcripts, along with the observation field notes, summer research proposals, implementation plans, and summer research posters were reviewed multiple times so that initial open codes can be developed (Glaser & Straus, 2006). To ensure that the codes developed were reliable, the research team independently coded one set of teacher data and compared their codes. From this collaboration, a comprehensive and cohesive list of codes was generated and used to code the remaining teachers' data. From the coding process, initial categories were developed regarding the participant's understanding of (1) interdisciplinary science inquiry, (2) their PCK as it relates to science and ISI, (3) the summer research experience and its perceived impact on their instruction, and (4) the factors that contributed or constrained their implementation of ISI in the classroom.

A 'cross-case analysis' using the constant comparative technique (Miles & Huberman, 1994) of each of the participant's interviews was used to identify aspects of their PCK, understanding of ISI, and summer research experience in relation to their classroom practice. Table 3 was set up to allow for the comparison of the different participants in relation to these different aspects. In addition to comparing the 10 teachers, comparisons were done of the same teacher with themselves in regards to each category over the course of their involvement in the project, to the five dimensions of Magnusson et al.'s (1999) model of PCK, and to the five orientations to teaching science that was developed by the research team during year 2 of the project (Liu & Nargund-Joshi, 2013). This analysis led to the classification of the 10 teachers into three categories in regards to their development of PCK and implementation of ISI within the classroom. From these categories themes were generated by comparing the categories with one another to understand the differences and similarities amongst the participating teachers as well as the patterns within and across the categories.

Study Limitations

This study examined the impact of authentic interdisciplinary science inquiry experiences on the development of in-service science teachers' PCK of ISI. Even though the study adhered to research protocol, several limitations need to be acknowledged. First, even though teachers volunteered to be involved in the project and signed a memorandum of agreement, the fidelity of that involvement in both their summer research experiences and subsequent implementation attempts were not consistent. As a result, while the initial population of the study was substantial, the final sample with which the study was able to study was small. Even so, the ten teachers highlighted in the

study were representative of the population and the number is typical when utilizing

grounded theory. Second, due to the constraints of the project and the teachers'

individual willingness to have research team members observe their classrooms, the

ability to generalize what aspects of ISI are present within their daily practice is limited.

The results therefore represent what was learned regarding teachers' understanding and

practice of ISI given a specific context.

<div align="center">**Findings**</div>

Overview

Analysis of the 10 teachers indicated that they could be classified into three

categories based on the development of their PCK as it relates to science and ISI and the

impact of their summer research experience. The categories include: stagnate (Emily,

Chris, Lynn, and Amy), the wobblers (Kristina, Anne, and Jeff), and the Trail Blazers

(Scott, Parker, and Mark). The features of these three groups in relation to (1) summer

experience and professed impact on teacher practice, (2) ISI as defined and evidenced in

practice, and (3) components of their PCK are explained as follows.

Summer Research and Professed Impact on Practice

The research experiences of the 10 teachers are summarized in Table 3. The

experiences of these teachers ranged from "traditional" research taking place within a

research laboratory to curriculum development that included the design of new tools,

laboratory exercises, and long-term projects.

<div align="center"><Insert Table 3 About Here></div>

Stagnate. The summer research experiences of Emily, Chris, Lynn, and Amy

included curriculum development of a high school anatomy and physiology course

(Emily), the construction of an economical and transportable earthquake shake table (Chris), and the genetic mapping of bacteria found within the local waterways of the Buffalo watershed (Lynn and Amy). While the experiences of these teachers were vastly different, how they viewed them impacting their practice and fitting into their curriculum was not. All four teachers highlighted in post-summer interviews from years 2 and 3 that the summer experiences exposed them to new laboratory exercises and provided them with new materials for their classrooms. Even though Amy and Lynn were involved in research that was more traditional in nature, the focus of this group was on the basic skills their students could learn and new tools they now had access to because of their involvement in the grant. These techniques and tools were also viewed to fit within only a specific unit of study. For Lynn and Amy, the unit was genetics. For Emily it was her 8th grade unit on human body and for Chris, it was his unit on plate tectonics. The focus was on developing exercises for a single concept and not on how their experiences from the summer translated into incorporating aspects of ISI within their entire curriculum.

Wobblers. The summer research experiences of Jeff, Kristina, and Anne ranged from research in a university materials chemistry laboratory and pharmacology/toxicology laboratory to coursework in integrating physics concepts in the classroom to middle school science curriculum development. Like the previous group of teachers, whilst these teachers were exposed to a wide variety of experiences commonalities exist in how they view those experiences impacting their practice and fitting into their curriculum. While there is still an emphasis on obtaining access to new technology and hands-on activities, the impact of their experiences on their practice extends also to how it enabled them to develop their own problem-solving and higher

order thinking skills. Jeff, Kristina, and Anne mentioned in the interviews that took place after their summer experiences that these experiences taught them to "think outside the box", use higher order thinking skills to develop a better understanding of what they were studying, to learn patience and to be more confident at trying out new ideas and activities.

Where this particular group of teachers illustrate "wobbling" is in the analysis of how they see their experiences fitting into their curriculum. In the interviews and implementation plans, these teachers state that they plan to or now include hands-on projects that are more inquiry in nature into many of their units, their focus is still on set skills for select units. The conception of integrating aspects of ISI as the foundation of how they structure their curriculum is not evident.

Trailblazers. The research experiences of Mark, Parker, and Scott over the two years of their involvement in the project included the collaboration with colleagues and university faculty to develop new engineering-based projects, observations of laboratories at a local cancer institute, research in a university pharmacology/toxicology laboratory, and to the development of a research-based project and small-scale Schleiren apparatus at a local, private industry. In post-summer interviews, these three teachers professed that their summer research experiences:

> (1) Taught them what is means to be a student again. As such they honed their
>
> problem solving skills, met dead-ends and frustrations that would allow them to
>
> better relate to those that their students met or would meet, and learned the value
>
> of constructing a direct product, rather than just stopping at the computer
>
> simulation phase.

(2) Were reminded what about what science really is through exposure to new

technology and the process of scientific inquiry.

(3) Encouraged them to think outside of their content area, or "content bubble" by

showing them that science does not exist in small 40-minute chunks. Science

exists on a much larger scale and students need to recognize the time and effort

that truly goes into doing science.

These three teachers illustrate the potential impact that participation in authentic research

experiences can have on the knowledge and beliefs that teachers hold. Like the other

teachers, they identified that their involvement in the project enabled them to access new

materials and tools for their classrooms. However, where they show themselves as

breaking away from the mindset of the previous teacher is by grasping that these

experiences offered more than just new project or ideas. Mark, Scott, and Parker were

able to explain how aspects of ISI could be incorporated into much of what they do in the

classroom by making small, yet significant changes in how they approached what is

meant to do science.

Interdisciplinary Science Inquiry – Professed Understanding and Evidence in

Practice

In terms of defining ISI, a commonality amongst all of the teachers highlighted

was that ISI involved incorporating other disciplines beyond the core content subject

being taught into their instruction. For example, that meant the inclusion of technology,

of other disciplines of science, of mathematics, and, in many cases, aspects of English

Language Arts. Also, 8 out of the 10 teachers professed that ISI involves introducing

students to topics that are not just abstract theory, but are relevant to their everyday lives

and are tangible, or in other words, the students can touch and manipulate what they are studying. The major differences within the three groups arise from (1) whether or not conception of ISI has changed over course of involvement in project, (2) the teachers' ability to articulate how the four elements are incorporated in classroom, and (3) what aspects are actually present in classroom practice.

Stagnate.

Defining ISI. Based on the interview transcripts and proposals from year two and year three there was no evidence of change in Emily, Chris, Lynn, or Amy's understanding of ISI. Whilst their descriptions of ISI include putting together different elements of science and technology, further investigation into what that means in terms of the 4 aspects of ISI reveal that their interpretation of these aspects of ISI do not align with the project's conception of ISI and as such can be considered to have a limited understanding of ISI. This limited understanding was evident in their articulation of how practices, crosscutting concepts, and the presence of ISI within different disciplinary core ideas, which is explained as follows.

Practices. The main emphasis that these teachers have on students learning the practices of science and engineering is in regards to having them learn specific skills. For example, learning how to use a microscope, take measurements, use a pipette, and use other instruments in the laboratory. Lynn justifies this position by emphasizing that her students cannot do inquiry because they lack the ability to perform these basic lab skills. Furthermore, these teachers' understanding of inquiry is limited. While Lynn acknowledges that she simply does not do it, Emily was not able to delineate what practices of science where present in her instruction, as she perceives inquiry as having

the students do something hands-on. Amy and Chris, on the other hand, view that inquiry is occurring when they ask the students questions.

   Crosscutting concepts. With these four teachers, crosscutting concepts is construed as crosscurricular. In other words, bringing in elements of math or English Language Arts (ELA), and in the case of Chris, social studies.

   "*ISI is a great way to teach because not only am I teaching it but the social studies hits it, math hits it."* (Chris, Fall 2013 Interview)

Crosscutting occurs when students are asked to write lab reports or use mathematical equations to solve a problem. Also, the ability to identify how these different concepts could be used in different units of study to allow students to see the bigger picture was not evident.

   "*It's so hard because I've been doing this for so long to even tease these out. It's just incorporated and it's what I do."* (Emily, Fall 2013 Interview)

   Disciplinary core ideas. In regards to this particular aspect of ISI, this group of teachers falls into two categories, much of which is based on their understanding of what ISI is. For Chris and Emily, who view ISI as bringing in other subject or doing something hands-on, ISI occurs all the time because students are doing something "hands-on" or does whenever he mentions a connection to another subject area, like social studies. For Lynn and Amy, ISI only fits into specific units, in their case genetics. This perception of where ISI is best taught is the rationale for why they proposed to do their summer research within the field of molecular biology.

   Observations of classroom practice. Teachers were asked to allow the research team to make observations in their classrooms when they were implementing aspects of

their summer research and/or thought the lesson illustrated ISI. Descriptions of these

observations as well as the aspects of ISI that could be identified in the lesson are

included in Table 3. Due to the constraints of the project and the teachers' individual

willingness to have research team members observe their classrooms, the ability to

generalize what aspects of ISI are present within their daily practice is limited. However,

by compiling the observations that did occur amongst Emily, Chris, Lynn, and Amy in

terms of the elements of each aspects of ISI that were present, one can start to see

patterns emerging. The frequency of each element of the 4 components of ISI is reported

in Table 4.

<Insert Table 4 About Here>

Purpose. More than half the time elements of this aspect were not present within

classroom instruction. The teachers' perceptions regarding the driver related to the

power of new technologies was based off of their use of technology that was "new" to

their classrooms. This technology included micropipettes, a spectrophotometer, and

probeware. Whether or not the view of "power of new technology" as use of technology

within the classroom can be interpreted as showcasing new technology that exists in

society is debatable. The other driver that was present during one observation is also

debatable as its presence was due to Chris lecturing to students on the worldwide effect

of El Nino. Students were not exploring for themselves this concept, rather they were

told of its existence and the impact that El Nino has on different parts of the world.

Practices. The most common practice evident within the observations that took

place was students carrying out investigations. In the original description of this practice

planning and carrying out are considered to be one practice, but as was evident in the

classrooms only students carrying out investigations was present. The other practices evident were all teacher directed. From their asking questions to pointing out specific aspects of data students either collected in their laboratory exercises or in practice problems that was important to constructing explanations from that data, the role of the students was of receiver rather than doer.

Crosscutting concepts. As existed with the practices of science within the teachers' classrooms, it was the teacher who acknowledged the existence of any of the crosscutting concepts. Those that were evident included observing patterns, recognizing relevant measures in size, and understanding the properties and functions of an object under study.

Disciplinary core ideas. Table 3 indicates the disciplinary core ideas that were apparent in the classroom lessons. No generalizations or commonalities were evident due to limited number of observations and to the range of subjects that these teachers taught.

Wobblers.

Defining ISI. Based on interview transcripts and proposals from year 2 and year 3 there is evidence that these teachers' understanding of ISI is not only starting to change, particularly in the case of Jeff, but their interpretation of elements of ISI more closely align with project's conception of this principle. However, elements not aligned with project's understanding of ISI are still present, particularly in conception of crosscutting concepts. Like the other teachers, these three describe ISI as integrating different elements of science into their instruction and, like those in the stagnate group, include mathematics and ELA in the description of interdisciplinary. Further investigation into their perception of the 4 aspects of ISI reveal that while they have more precise

understanding of ISI, there are still elements that reveal either a misconception or limited understanding of.

Practices. The focus of learning the practices of science remains on having students learn specific skills and techniques. However, it is learning them within the realm of conducting experiments and completing research projects and added to learning basic lab techniques students should be learning how to analyze and interpret data, find patterns in the data and being able to come up with conclusions.

Crosscutting concepts. While Kristina still views crosscutting to mean incorporating social studies, math, and ELA, Jeff and Anne perceive this to mean bringing back or tying together concepts that students already know or have learned in previous units. However, neither Jeff nor Anne was able in the interviews to fully articulate what that means in regards to the curriculum that they teach.

Disciplinary core ideas. For these teachers, ISI translates into topics from the general standpoint of engaging students in hands-on experiments. This is particularly the case for Kristina and Anne, who explained that by adding an experiment or demonstration to a unit, any unit, students are able to engage in doing ISI. Jeff, while stating the ISI is more easily presented more in general topics, was able to go on and state how it could be incorporated into specific units, such as electron configuration and the need to understand principles of physics or organic chemistry and the important connection that can be with biology.

Observations of classroom practice. Descriptions of the observations that took place in Jeff, Anne, and Kristina's classrooms as well as the aspects of ISI that could be identified in the lessons are included in Table 3. Whilst the some constraints were still

apparent in regards to having the research team observe their classrooms, these teachers' apprehension towards and blocking of such observations was not as evident as those within the stagnate group. However, as was the case with the four previous teachers, the ability to generalize what aspects of ISI are present within their daily practice is limited. To try and identify if any patterns existed amongst these three teachers, the elements of each aspects of ISI that were present was compiled. The frequency of each element of the 4 components of ISI is reported in Table 4.

Purpose. Within the observed lessons, all 4 drivers were present, though low in frequency. Less than half the observations did not connect to at least one driver. There was a shift from stagnate group in that here the drivers were evident within what the students were experiencing on their own or with the aid of their teacher. No longer were these elements being identified or studied purely by the teacher.

Practices. As was the case with identifying the drivers of ISI within the lesson, all observed lessons involved at least one practice of science and there was a greater orientation to students-directed learning rather than teacher-directed. The most evident was the carrying out of investigations. There was still no evidence of planning investigations. What was not apparent in the previous group but is with this group are student questioning, the development and use of models by both the teachers and students, students having to construct explanations of what they were observing and having students engage in developing an argument from evidence.

Crosscutting concepts. Within the observations that took place of these three teachers, evidence of crosscutting concepts present within the lessons was not evident 71% of the time. This lack of inclusion was based on how the project defined

crosscutting concepts and may be due in part to the teachers' understanding of crosscutting to incorporate math and ELA.   What was evident to a greater degree was that those that were present were student-orientated or directed in that students were asked to identify properties and functions and to construct explanation of how the different size, structure, and weight of their buildings affected their ability to withstand shaking.

Disciplinary core ideas. Table 3 indicates the disciplinary core ideas that were apparent in the classroom lessons. There were no generalizations or commonalities evident due to limited number of observations and to the range of subjects that these teachers taught.

Trailblazers.

Defining ISI. Based on interview transcripts and proposals from Y2 and Y3 there is evidence that these teachers' understanding of ISI was either originally well-aligned with the project's conception or through their involvement has adapted in such a way that there is greater clarity or understanding in regards to what ISI is and its' impact on student learning. In particular, Scott and Parker initially did not have clear or well-aligned understandings of ISI, but acknowledged that as they have been involved in this project, their understandings have changed.

> Scott: *ISI is really science...It is not English and math.* (Fall 2012) *It's different fields of science tied into engaging lessons, right, that are student-centered, they're hands-on experiences, they're developing a purpose – ya know, a lot of this is student-centered, right, more open-ended project-based but across the disciplines of science. And so its not just biology or not just physics, but projects*

that encompass all of them and also have a technology piece as much as possible.

(Fall 2013)

Practices. Connected to how the professed purpose for doing ISI are the practices of science and engineering that they identify as essential for their students to learn. They include letting the students design their own experiments, letting them find their own answers, set up students for failure so that they learn to problem solve, and that they communicate what they have learned and reflect on the process. Here the emphasis remains student centered and while Scott does identify that students need to learn skills, those skills are meant to develop through the process of student-designed experiments.

Crosscutting concepts While Scott still perceives crosscutting concepts to be the inclusion of chemistry and physics in different biology units, Mark and Parker relate C.C. to be the integration of key concepts and ideas from other sciences into their lessons. These key concepts are underlying principles that are important to many areas of study. Mark highlights the importance of students in CAD utilizing their knowledge of forces from physics and angles from trigonometry. Parker highlights that concepts such as energy and force need to be addressed beyond their respective units. For example, energy should be discussed when students study motion, forces, electricity, magnetism, and waves.

> *When you leave the questions open, and you give the students the freedom to sort*
>
> *of think on their own, I find that that's one of the best sources of additional*
>
> *content.* (Parker, Fall 2013 Interview)

Disciplinary core ideas. For both Parker and Mark, ISI translates easily into the courses that they teach. For Mark, his engineering design courses easily lend themselves

to incorporating aspects of ISI. The same exists for Parker who teaches conceptual

physics and medical physics. For Scott, ISI can be translated into specific unit of his 8th

grade living environment course, such as the unit on cells, and for 7th grade science

through the use of Science Olympiad projects.

   Observations of classroom practice. Descriptions of the observations that took

place in Mark, Scott, and Parker's classrooms as well as the aspects of ISI that could be

identified in the lessons are included in Table 3. As was the case with the previous group

of teachers, whilst the some constraints were still apparent in regards to having the

research team observe their classrooms, these teachers' apprehension towards and

blocking of such observations was not as evident as those within the stagnate group.

However, the ability to generalize what aspects of ISI are present within their daily

practice is limited, therefore the presence of different aspects of ISI from their lessons

were compiled to try and identify whether or not any patterns existed amongst these three

teachers. The frequency of each element of the 4 components of ISI is reported in Table

4.

   Purpose. Within the observed lessons, all drivers but inherent complexity of

nature and society were present, with less than a quarter of the observations not

connecting to at least one driver. Continuing with the shift seen in the Wobblers group, it

was in these classrooms the drivers were evident within what the students were

experiencing on their own or with the aid of their teacher.

   Practices. All observed lessons involved at least one practice of science and as

was the case with the Wobbler's classroom, these observations evidenced a greater

orientation towards a student-directed use of them. While the most evident practice was

the carrying out investigations, there was still no evidence of planning investigations.

What was not apparent in the previous groups but was with this group the greater

emphasis on having students analyze and interpret data and construct explanations of

what they were observing. What was unique to these observations was that students were

verbally and on paper communicating their findings/understanding of what was being

studied.

Crosscutting concepts. Unique to this group of teachers as well was the evidence

that all of the observed lessons involved at least one crosscutting concept. It was also

apparent that these concepts were being identified by the students either on their own or

with the aid of their teacher. The most evident crosscutting concept was observing

patterns. Others that were present included recognizing relevant measures of size, time,

and energy, defining the system under study, and understanding properties and function

of an object under study.

Disciplinary core ideas. Table 3 indicates the disciplinary core ideas that were

apparent in the classroom lessons. There were no generalizations or commonalities

evident due to limited number of observations and to the range of subjects that these

teachers taught.

Patterns Present and the Development of Pedagogical Content Knowledge

Stagnate. As name of this group implies the professed understanding/conception

of different elements did not change over the course of the teachers' involvement in the

project. Emily, Chris, Lynn, and Amy's professed understanding of the five aspects of

PCK as defined by Magnusson et al. (1999) are described in Table 3. Their professed

conception of these aspects as they relate to science and to ISI remained the same in the

semi-structured interviews and observations that took place during year 2 and 3 of the project. Upon examination of these aspects in respect to the observations that took place in their classrooms, these four teachers can be viewed as being primarily traditionally oriented in both their beliefs and practice. The key features of their PCK include: (1) teacher as knowledge-holder, (2) students must be taught – need for explicit instruction, (3) doing inquiry is doing something hands-on in the classroom, (4) exam-driven curriculum. Figure 1 represents these features as well as elements of the teachers' practice and interview excerpts that supported this particular categorization of their PCK.

<Insert Figure 1 About Here>

Wobblers. The wobblers earned their name not only for their ISI implementation strategies, but also for the development of their PCK as it relates to science and ISI. Jeff, Kristina, and Anne's professed understanding of the five aspects of PCK as defined by Magnusson et al. (1999) are described in Table 3. Overall, whilst the three teachers in the group profess to hold student-centered and constructivist-based beliefs regarding how they teach science, their practice still shows evidence of a more traditional, teacher-centered style of teaching. Whilst this is the case, all three have professed and shown over the course of their involvement in the project a gradual inclusion of practices that better align with their professed beliefs regarding their orientations towards teaching science and, more importantly, how students learn. Figure 2 represents the key features of Jeff, Kristina, and Anne's PCK as supported by evidence from their practice and interview excerpts.

<Insert Figure 2 About Here>

Trailblazers. This particular group of teachers initially showed evidence of more developed understanding of PCK as it relates to their subject area in the PCK assessment that was given in July 2013. Whilst qualitative evidence of development or change is not currently available at this time, observations of their classroom practice illustrate it is most strongly aligned to their professed PCK in comparison to the other teachers highlighted. Mark, Scott, and Parker's professed understanding of the five aspects of PCK as defined by Magnusson et al. (1999) are described in Table 3. Figure 3 represents the key features of their PCK as supported by evidence from observations their practice and interview excerpts.

<Insert Figure 3 About Here>

Discussion

In analysis of the findings three main themes emerged. These themes can be summarized as:

(1) The development of in-service science teachers' PCK is not a linear progression.

(2) Teachers' experiences in science and engineering act as filters in their perception and translation of ISI into a K-12 science classroom.

(3) The dynamic interplay of core features of the professional development model and contextual factors impact implementation of ISI within the classroom.

The Development of In-service Science Teachers' PCK is not a Linear Progression.

The model proposed by the project illustrated a linear progression of teacher professional development opportunities to improved teacher knowledge and skills in science inquiry and inquiry science teaching to improved student science achievements, as measured by NYS science examinations. This study examined the first progression,

from professional development to improved teacher knowledge and teaching skills in interdisciplinary science inquiry. Overall, analysis of the 10 teachers highlighted in the study indicate that the involvement in the summer research experiences did not have any consistent effects on the development of their PCK as it relates to ISI. Furthermore, the progression of involvement in professional development to the development of teacher PCK is not linear.

The teachers who were identified as stagnate did not illustrate any significant qualitative changes in their PCK over the course of the two years. These teachers still maintained a teacher-centered, traditional view of teaching science that did not align with the project's perception of ISI or with a student-centered, inquiry-based approach to teaching. Even though these teachers had access to and used new materials and laboratory exercises in their classrooms, the nature in which these new resources were utilized were indicative of a highly structured, teacher-mediated learning experience. Student exploration and discovery was overshadowed by the need for students to learn basic skills and follow a set of prescribed directives. A study done by Gilbert and Yerrick (2001) found similar findings in that the teachers emphasized the students' needs to know the "basics" before they could attempt to practice inquiry science.

The Wobblers, particularly in the case of Jeff and Kristina, illustrate teachers whose orientations to teaching science and perception of their how their students learn best do always not match how science is taught in their classrooms. The nature of Jeff and Kristina's summer research may have also led to this disconnect as both were involved in more traditional research experiences and struggled with how that would translate into their classrooms. Anne, on the other hand, spent the summer working

alongside colleagues on enhancing their science curriculum through the implementation of more technology and inquiry-based activities. She attributed her ability to implement these types of activities to her summer work and the guidance of her coordinating teacher and the graduate STEM students who worked alongside her in the summer and in her classroom during the school year. These three teachers illustrate a slowly progressing development in their PCK as it relates to science. While they worked towards implementing more inquiry-based lessons into their instruction, there are aspects of their understanding of ISI that are still not well aligned with the four components of ISI and instruction that held onto a more traditional style of teaching science.   The disconnect between professed orientations towards and beliefs about teaching science and the actual practice that takes place within the classroom is well supported by research in teacher beliefs and practice (Mansour, 2013; Mellado, 1998; Savasci & Berlin, 2012).

The teachers who initially scored higher on the PCK assessment did not necessarily illustrate significant growth in their PCK over the course of their involvement in the project. These teachers, who already illustrated an inquiry-based, student-centered orientation towards teaching science, were, however, more willing to make changes in their instruction. The professed impact of the summer research experiences on these three teachers illustrate the potential that providing classroom teachers with opportunities to participate in authentic science or engineering enterprises can reassert the need for science in the classroom to be student-centered, inquiry-based, and integrate multiple disciplines and perspectives in a way that mirrors science in today's society. The findings regarding these teachers are consistent with those found by Luft (2010). In her study regarding the impact of inquiry-based demonstrations classroom program on the

beliefs and practices of secondary science teachers, she found that involvement in the program led to more change in the practices than beliefs of the experienced teachers. The beliefs held by the experienced teachers enabled them implement extended inquiry cycles in their practice.

Teacher Background as a Filter to Teachers' Perception and Translation of ISI in K-12 Science Classrooms

Interdisciplinary science inquiry, as defined by the ISEP research team, is framed within the continuum of integrated science (Fogarty, 1991; Klein, 1990, 1996; Petrie, 1996; Lederman & Niess, 1997) and the next generation science standards (NRC, 2013). As such, ISI consists of four dimensions: (1) the purpose (i.e. drivers) of ISI; (2) science and engineering practices; (3) crosscutting concepts; and (4) disciplinary core ideas in life science, physical science, earth and space science, and engineering and technology.

The aspects of this framework that were most evident and translatable for all of the teachers highlighted were integrating the practices of science and the importance of connecting science in the classroom to students' lives and communities (i.e. purpose or drivers of ISI). For many of the teachers, the practices of science were simply a rewording of the scientific method, which is a concept that they all felt they taught well within their courses. Even though all the teachers felt comfortable with these practices, it was evident that how they were implemented in their classrooms was not the same. For the stagnate teachers, these practices were taught as basic skills that students needed to learn in a directed step-by-step process. Students were given questions to explore, prescribed procedures to follow, and, in several cases, the "findings" they should have found. These teachers highlight that even when students are doing something "hands-

on", they may not be experiencing interdisciplinary science inquiry, which appeared to be a common conception of the teachers in this group. The observations of the wobbling teachers classrooms indicated that even though their students did not experience all of the practices of science, the lessons they implemented allowed for more student direction. The trail blazing teachers, on the other hand, were focused on allowing students to designing the process, experiment and test their ideas, fail, make revisions, and come up with their own conclusions based on what they experienced.

The main aspect of ISI that the teachers struggled with in their understanding and in implementation was the crosscutting concepts or unifying themes in science and engineering. For many of the teachers, crosscutting concept was construed as cross-curricular. Therefore, in their descriptions of what a crosscutting concept meant to them and how they were implemented into their classrooms, they focused on how they incorporated English Language Arts techniques and mathematics. In one of the cases, social studies was even mentioned as being "crosscutting". When teachers were shown or told of the list of seven crosscutting concepts and their descriptions, most, with the exception of the trailblazer group, would make comments like "oh yeah, I teach that here…" The focus of these concepts was not on how they could be unifying themes across the different disciplines of science or even within a single discipline of science, but on a single topic. This singularity in understanding may be due to the background these teachers have in studying and teaching a single discipline of science. For the teachers who do teach another subject area outside that discipline, such as environmental science, it is taught within the confines of the district's pacing guide (i.e. mandated curriculum). This particular finding has implications for how secondary science teachers

are taught to teach science within their education programs. Focus within a single discipline, such as biology or chemistry, may not be sufficient in the future if teachers are being asked to implement a reform-based, spiral curriculum where these unifying themes develop over time and link together different disciplines of science.

Within the trailblazer group, two separate pathways were evident. Scott initially construed crosscutting to mean cross-curricular with ELA and math, in the first year of his involvement his understanding of what crosscutting meant changed and more closely mirrored that of the project in terms of the integration of different disciplines of science. He still however, did not articulate clearly how the different crosscutting concepts could be used within his classroom as a way for students to grasp how the "big picture". Mark and Parker, from the beginning, were able to explain a more exact understanding of what crosscutting concepts were, as defined by the project, and how they could be and were implemented into their classroom practice. The ability of Mark and Parker to explain how crosscutting concepts could be used within their practice may be attributable to their own backgrounds and the nature of the curriculum that they both teach. Both teachers have physics and engineering education backgrounds. Mark teaches senior-level engineering and Parker teaches conceptual physics and medical physics to high school students. Even though very different in nature, their summer research experiences focused on the application of different physics and engineering principles. Their physics background and research experiences seems to help with their understanding of unifying themes, particularly energy and forces.

Dynamic Interplay of Core Features of the Professional Development Model and Contextual Factors Impact Implementation of ISI within the Classroom

Using the model for studying professional development proposed by Desimone (2009), the core features of the project that were identified and analyzed to determine whether or not they contributed to the development of the participating science teachers' PCK. Desimone (2009) identified 5 core features of effective PD: content focus, active learning, coherence, duration, and collective participation (p. 184). Examining the original model of the project, Desimone's five core features could be redefined into (1) the summer research connection, (2) collaboration between STEM students and in-service science teachers, (3) an active learning environment, (4) coherence and (5) duration. These core features interplayed with one another in various ways leading to varied changes in teacher knowledge regarding the practices of science and engineering as well as ISI that in turn did or did not lead to changes in their practice.

Looking first to how involvement in the project led to increased knowledge and practice, the core features that appeared to have the greatest impact were the summer research connection to the teachers' curriculum and coherence between the aspects of ISI and the teachers' orientations towards teaching science. Even though the teachers professed to have learned new ideas and skills over the course of their summer research experience, the connection between those experiences and the teachers' curriculum played a significant role in whether or not the teachers attempted to implement those newly learned skills within their classrooms. The teachers who professed that the research experiences had direct connections to specific aspects their mandated curriculum were those that were most likely to change aspects of their practice. Similar findings emerged from the work of Osborne, Simon, Christodoulou, Howell-Richardson, and Richardson (2013) who attributed their inconsistent and inconclusive findings in part to

the lack of a specific content focus in regards to developing teachers' use of

argumentation and a more dialogic and interactive pedagogy. According to these

researchers,

> the *sine qua* non of professional development has to be first building an
>
> understanding for teachers in well-articulated and clear terms of the underlying
>
> theoretical rationale and the empirical evidence to justify the value of acquiring
>
> the new practice or practices. (p. 338)

Additionally to aid in the implementation of reform-based practices, the development of

curriculum materials that are aligned with ISI needs to be provided to teachers (Krajcik,

McNeill, & Reiser, 2008). For the teachers who struggled with how their research

experiences connected to their curriculum, additional and more specific models and

practice should be provided to aid them in the transition of applying ISI-perspectives and

experiences in their classrooms.

The impact of coherence between the teachers' orientations towards teaching

science, how students learn science best and the aspects of ISI was most evident in the

comparison between the stagnate group of teachers and the trailblazer group. The

stagnate group's teacher centered and traditional orientations towards teaching science

was a stumbling block for their successful implementation of ISI in their classrooms.

The trailblazers' orientation, on the other hand, enabled them to make changes in their

practice. This was evidenced by the implementation of new laboratory activities that they

had developed and practiced over the course of their summer research experiences, of

new skills and technology in the classroom, and their increased effort to establish

connections between science content, current research in science and engineering and to

students' lives. This finding is supported by the research done regarding the relationship between teacher beliefs and practice (Haney et al., 1996; Mansour, 2010; Mansour, 2013). According to Mansour (2010), science teachers' pre-existing beliefs, if they do not match the underlying philosophy of new curriculum or reform initiatives, can thwart successful implementation.

The other core features also played a role in the progression of professional development opportunities to change in practice. In particular, for several of the teachers the summer research experience offered them the opportunity to become engaged in a collaborative and active learning environment. The roles were reversed as the teachers were asked to become students again as they worked alongside research faculty, STEM students, and their colleagues. The teachers were exposed to completely new areas of scientific research, technology, and often skill sets that put that back into role of learner. With that came the frustrations of learning something new as well as ultimately the sense of success when those skills were mastered. The active learning environment, rather than the passive transmission of information provided the teachers with a more meaningful and authentic learning experience that for several teachers served as a model for how to implement ISI within their classrooms. Mark, in particular, highlighted how his frustrations and failures with designing and building the boomilever was a valuable asset in helping his students with the same process during the school year.

Even though it was implied within the original model proposed by the project, participation did not always lead to change in participating teachers' knowledge and beliefs regarding interdisciplinary science inquiry or within their practice. Over the course of the two years of full implementation, 72 % of the teachers could be classified as

stagnate. Upon analysis of the teachers' interviews several contextual factors were identified as constraining the teachers' perceived ability to implement aspects of their summer research and/or ISI in their classroom. These factors included (1) the lack of coherence between the teachers' research experience and the areas of science with which they taught; (2) the teachers' beliefs regarding their summer experience and their own abilities to translate those experiences into the classroom as well as their students' abilities to do inquiry; (3) the teachers' knowledge of ISI as a limiting factor into their ability to find or perceive the relevance of the summer research experience; (5) students' overall academic weaknesses, particularly in mathematics and reading; (6) the time required to develop and implement activities or lessons that were based on either the teachers' summer research experiences or ISI, in general; and (7) the lack resources, in terms of equipment, needed to successfully implement the teachers' summer research experiences.

Conclusion

Interdisciplinary science inquiry, which is implied in the Next Generation Science Standards, represents a conceptual shift in how science should be taught in K-12 schools in the future (NRC, 2011). As science teachers are asked to develop and implement curriculum that emphasizes inquiry across disciplines, incorporate engineering and technology, whilst asking students to solve real-world problems utilizing the knowledge and skills they have learned, the way with which teachers approach teaching science may need to change. The research is intended to illuminate the factors involved in this process of change in such a way to provide insight into the development of science teachers' PCK on ISI as they take part in the interdisciplinary research process. With the understanding

that buy-in and implementation of interdisciplinary science inquiry will vary amongst the participating science teachers, it is important to delve beyond the surface of whether or not change happens to begin to develop an understanding of the mechanism(s) underlying and factors responsible. As standard-based reform within the United States continues on its path of reforming science teaching and learning through scientific and interdisciplinary scientific inquiry in science classrooms, the value of understanding how teachers perceive and enact ISI for learning will be a main predicator in the success of these new reforms on impacting student science achievement.

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