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Examining Science Teachers' Development of Interdisciplinary Science Inquiry Pedagogical Knowledge and Practices

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Abstract The current literature relates to how teachers develop knowledge and practice of science inquiry, but little has been reported on how teachers develop interdisciplinary science inquiry (ISI) knowledge and practice. This study examines the effect of university research experiences, ongoing professional development, and in-school support on teachers' development of ISI pedagogical knowledge and practices. It centers on documenting diverse teachers' journeys of experiencing ISI as well as developing knowledge of ISI. It was found that there was variation in ISI understanding and practice among the teachers as a result of the combination of teachers' experiences, beliefs, and participation. Thus, in order to help teachers develop ISI knowledge and pedagogy, barriers to ISI knowledge development and implementation must also be addressed. Professional developers must articulate clear program goals to all stakeholders including an explicit definition of ISI and the ability to recognize ISI attributes during research experiences as well as during classroom implementation. Teachers must also be held accountable for participation and reflection in all aspects of professional development. Program developers must also take into consideration teachers' needs, attitudes, and beliefs toward their students when expecting changes in teachers' cognition and behavior to teach inquiry-rich challenging science.

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Introduction

Research shows that teaching inquiry-based science is complex; science teachers typically have a poor understanding of inquiry and are unable to implement inquiry science teaching in their science classrooms (National Research Council [NRC], 2000; Wallace & Kang, 2004; Windschitl, 2004). Because teachers lack knowledge on science inquiry, the quality of current high school experiences of inquiry is poor for most students.

The National Science Education Standards (NRC, 1996) recommend that professional development (PD) for teachers of science should help them (a) learn science through inquiry, (b) learn how to teach science through inquiry, and (c) become lifelong "inquirers." The need for PD education in inquiry science teaching is further highlighted in the just-released Next Generation of Science Standards (NGSS, 2013) which elaborates a new vision of science competence that may be described as interdisciplinary science inquiry (ISI).

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 USA in the future (NRC, 2011). In order for this new form of inquiry to be successfully implemented into classrooms, teachers must not only be aware of the skills and mindsets necessary to conduct it, but also how it translates into the lives and needs of their students.

Although the term "interdisciplinary" has existed for a long time, the exact meaning of ISI in the literature remains unclear. Other terms such as multidisciplinary, transdisciplinary, and integrated science (Davison, Miller, & Metheny, 1995) are used interchangeably (Czerniak, 2007; Richards, 2008) to define interdisciplinary. Czerniak (2007) suggests that many teachers do not have an understanding of integrated science; therefore, a clear definition could provide the stimulus for the design and further research regarding the impact of ISI curriculum and instruction. The necessity for a clear definition and understanding of integrated science are the goals of this study, and the results will have substantial significance for ISI curriculum and instruction.

The report on Facilitating Interdisciplinary Research (CFIRCSEPP, 2004) describes multidisciplinary research as "involve[ing] more than a single discipline in which each discipline makes a separate contribution. Investigators may share facilities and research approaches while working separately on distinct aspects of a problem (p. 27)." More specifically, the report defines Interdisciplinary Research (IDR) as:

> Interdisciplinary Research (IDR) is a mode of research by teams or individuals who integrate 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.

Our conception of the term ISI is drawn from the strands of scientific proficiency (NRC, 2007), project-based science learning (Krajcik & Czerniak, 2007), "Facilitating Interdisciplinary Research" by the National Academics Committee on Science, Engineering, and Public Policy report (COSEPUP, 2005), and the Next Generation of Science Standards (2013). Specifically, the three dimensions of the science competence from the next-generation science strands (i.e., disciplinary core ideas, science and engineering practices, and crosscutting concepts) are emphasized. This understanding of ISI also highlights key features of project-based science learning that emphasizes relevance to student lives through identifying and answering appropriate driving questions by engaging students in multifaceted inquiry, collaborating through a professional learning community, and using technology to investigate, develop artifacts or products, and collaborate and access information. Therefore, our definition of ISI consists of the following attributes:

- A contextualized nature of problems which establishes relevance to students' lives
- Incorporation of inquiry and engineering process skills or practices to learn science
- Creating connections within and across disciplines such as Mathematics, English Language Arts, Engineering, and Science, and
- Anchored within specific science disciplines.

The purpose of this study is to examine the development of teachers' ISI knowledge and the resulting instructional practices within the classroom. The focus lies in examining changes in instructional strategies that exemplify ISI as a result of participation and involvement in summer research at the university with scientists as well as through participation in PD during the school year. This study aims to answer the following questions.

(a) How is a teacher's knowledge and understanding of ISI impacted as a result of university research and follow-up in-school support?
(b) How is a teachers' knowledge of ISI demonstrated through their teaching strategies?

Literature Review

The development of ISI and context-based PD relies on partnerships built in professional learning communities to support teachers in the process of learning, growth, and change. The National Science Foundation (NSF) has invested heavily on innovative partnerships with the goal of improving K-12 student achievement in science and mathematics through such partnerships (National Science Foundation, 2014). Given that the nature of school–university partnerships have been characterized as collaboration at best and exploitation at worst (Miller & Hafner, 2008) and knowing that partnerships are becoming one of the options for turning around the lowest performing schools in economically challenged communities, it is essential that the unique aspects of each community make critical contributions to all collaborative efforts. Linking the community to school improvement can improve the healthy development of children so that they come to school better equipped for learning, it can foster parental and community participation and understanding in the education of children and the work of schools, it can work to transform the culture of schools, and it can help build a political constituency to support public education (Warren, 2005).

A key feature of such partnerships is the creation of professional learning communities whose primary role is to cultivate mentoring partnerships between middle and high school teachers, but to also add parents and students; university faculty; university graduate and undergraduate students and volunteer STEM (Science, Technology, Engineering and Mathematics) professionals. Having shared goals within all stakeholders can lead to the development of successful school reform.

A critical element of successful PD is to be mindful of the culture of the school. From this perspective, VanDriel, Beijaard, and Verloop (2001) discuss a top-down approach to reform movements which often lead to failure of successful implementation by teachers because the developers know by assuming how teachers can change their classroom behaviors. This approach often leads to failure due to the fact that the curriculum or program developers often fail to take into account the teachers, students, and the culture in which the new curriculum or practices have to be embedded. It has been argued that the culture of “school science” may restrict PD of science teachers as is seen in many programs and initiatives (Munby, Cunningham, & Lock, 2000).

Research has also found that the success of PD programs is also largely affected by teachers’ beliefs about student learning which play an important role in their successful integration of new curricular materials (Nargund & Park Rogers, 2010). Research about teacher beliefs demonstrates that although PD interventions can support and enhance teachers’ learning of science, deeply rooted beliefs about science and the nature of science is often unaffected by most PD involvement (Yerrick, Parke, & Nugent, 1997). Therefore, several studies suggest that PD programs consider teachers’ prior knowledge, beliefs, and everyday school practice in order for it to be successful. They must take into account the diversity of behaviors and beliefs of their participants (Cotton, 2006). According to Coenders, Terlouw, and Dijkstra (2008), beliefs act like a filter through which new knowledge is interpreted and implemented. Mansour (2009) states that “beliefs become personal pedagogies or theories to guide teachers’ practices: Teachers’ beliefs play a major role in defining teaching tasks and organizing the knowledge and information relevant to those tasks.” These personal pedagogies are played out in the day-to-day decisions that teachers make concerning what to teach, what to skip, and how much time and attention will be given to certain topics of study (Cronin-Jones, 1991).

Taking into consideration the challenges that arise as changes in teacher practices are implemented, PD does result in effective and beneficial outcomes. Longitudinal studies have emerged, which have linked sustained increases in student learning of science for teachers who have participated in science teacher PD (Johnson, 2006). The literature regarding improving teacher knowledge development points to aspects of PD that leads to positive outcomes as well as those that need tending to. However, there is scant evidence of teachers participating in PD related to exposure to ISI as highlighted in the new standards documents. This particular study documents teachers involved in a unique opportunity to engage in PD that highlights the processes of ISI.

We have identified the processes of PD that were successful as well as those that were challenges. We hope this knowledge will inform the direction of PD programs aimed at increasing teachers' knowledge and practice of ISI.

Methods

This study was a qualitative, interpretive, multiple case study of three high school science teachers. This form of case study approach allows researchers to investigate a phenomenon, population or general conditions (Glesne, 2006). Yin (1994) describes a case study approach as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (p. 13). As a result of using this approach, a deeper understanding of "why" and "how" the summer research experiences impacted teachers' pedagogical content knowledge (PCK) as it relates to their understanding and implementation of ISI practices is explored.

Context and Participants

A NSF-funded partnership termed ISEP (Interdisciplinary Science and Engineering Partnership) was established in 2011 between two northeastern universities and a local urban school district. The project's goal was to integrate the latest ISI and engineering research approaches in science education by providing teachers with PD and research experiences. Professional learning communities which support continuous growth and development of a teacher's ISI knowledge and help in development of PCK specific to ISI were also an integral part of this project although not a specific focus of this paper.

The participants in the study compromised a total of 58 in-service teachers who currently teach in the 12 public middle or high schools in a large city in the northeastern region of the USA. These teachers took part in summer research experiences with scientists who were actively conducting research in a wide variety of STEM fields. Purposeful sampling of three participating teachers highlighted in this study illustrates the spectrum of knowledge of ISI instructional strategies and resulting implementation. Background details on the three selected participants are summarized in Table 1.

The teachers serviced students from lower socioeconomic status and racially diverse schools which were particularly challenging for students and teachers, socially and academically. Once enrolled in the partnership, the teachers participated in a variety of research and PD experiences aimed at increasing their knowledge, understanding, and practice of ISI.

Data Collection and Data Analysis

Data Collection

Multiple sources of data were utilized, including written questionnaires from teachers focusing on their preconceptions of ISI, their summer proposals for

Table 1 Background of participants

Background information of participant teachers						
Name	Gender	Race	Type of school	Profession/s	Subject taught	No. years teaching
Jack	Male	White	High school	Welder/science teacher	Environmental/ earth science	15
Chris	Male	White	High school	Criminal justice/ science teacher	Biology	11
Stash	Male	White	Middle school	Science teacher	Integrated science	12

entrance into the summer research, summer research observations, reflective log sheets, summer research posters, and classroom observations. Semi-structured interviews with teachers and students were also conducted. Ongoing PD workshops also provided feedback from teachers through workshop evaluations.

Many experts indicate that multiple data sources provided a rich resource for triangulation by converging information gathered by different methods such as observations and interviews (Ely, Anzul, Friedman, Garner, & Steinmetz, 2006). The multiple sources of evidence in case studies allow an investigator to address a broader range of historical, attitudinal, and behavioral issues. The advantage to using multiple sources of evidence is the development of converging lines of inquiry, a process of triangulation. The examination of the evidence from different perspectives will increase the chances that a case study will be exemplary (Yin, 1994). A chain of evidence demonstrates to us that the researchers attended to the validity of the research process (Yin, 1994). As it pertains to this study, triangulation of the variety of data sources mentioned below substantiated themes and conclusions that were formulated in teachers' development of ISI content as well as pedagogical knowledge. Table 2 provides a summary of the data sources as well as an explanation of its purpose.

One major area of support for teachers to help translate their summer research experiences into practice came from the monthly workshops that the research team had designed and implemented. The overarching goal for the workshops was a three pronged approach which aimed firstly to increase teacher knowledge about the ISI framework and the ways in which it connected to the existing local, state, and national standards so teachers were not overwhelmed at the idea of a brand new set of standards to teach. The second goal focused on having teachers experience ISI activities and engage in identification of ISI characteristics within science inquiry activities and lastly to have teachers receive support in designing their own ISI-related classroom activities reflecting their summer research as well as creating rubrics for assessing ISI in the classroom lessons (see "Appendix" for the specifics of the PD workshops).

Data Analysis

Data analysis for this study was carried out through a series of codes and themes based on the original research questions. We utilized Creswell's (2006) explanation of direct

Table 2 Data sources and purpose/explanation

Data sources	Purpose/explanation of data source
Proposals	Data analysis began with a look at teachers' initial proposals in which they were asked to explain their understandings and conceptions of ISI
Teacher log sheets	During their summer research experiences, teachers were required to fill out log sheets used as reflections on their daily summer research experiences. The log sheets focused on the K-12 framework drivers such as the science and engineering practices, crosscutting concepts and also included an area for personal written reflections which asked them whether they had achieved the overall goals of the sessions and how they planned to utilize this experience within their classrooms
Poster presentations	At the conclusion of the summer research experience, teachers were required to create posters representing a summary of what they did. These posters were presented and shared during a poster presentation event. The posters provided data on teachers conceptions of ISI as a result of summer research and the ways in which they connected it to the proposed classroom implementation
Professional development workshops	Teachers were also given the opportunity to engage in ongoing monthly PD offered to them by the research team at the university. The research team conducted these workshops on various topics to assist teachers in further understanding of ISI and to support implementation of ISI strategies in their classrooms. The topics of the workshop included Understanding ISI; understanding the role of the professional learning communities that the teachers were involved in; evaluating ISI; project-based science framework and applications within ISI and focusing on the next generation of science standards, ISI framework and the common core curriculum standards. teachers filled out evaluations based on individual workshops that provided us with feedback on their experience and understanding of each workshop and how they would translate this into classroom instructional strategies and lesson
Classroom observations	Classroom observations were utilized to demonstrate teachers' understanding of ISI through their summer research experiences and how they translated it through their instructional strategies within their classrooms. There were three aspects that resulted from the analysis of teacher classroom observations. These were an especially valuable data source since they represented a culmination of the teacher's experiences and translation into the classroom via instructional practices reflecting ISI. Data supported teachers' development in three critical areas. They focused on the teachers' development and knowledge of science content, pedagogy and the effect they had on the learning of their students determined by contextual factors, milieu, beliefs, and knowledge of their students

interpretation. In this interpretation, the researcher pulls data apart and puts them back together. The variety of raw data was collected and sorted through by pulling it apart and searching for codes that occurred repeatedly. These codes then helped to formulate succinct themes that were put back together. In this way, our explanations were informed by direct interpretation. We then looked at the themes that were formed as a result of initial analysis and tried to find connections or contradictions in the data (Seidman, 2006) through repeated rounds of analysis and interpretation.

Specifically, data from research proposals, research observations, log sheets, poster sessions, during the summer were summarized and analyzed to view how the teachers conceptualized ISI understandings during their summer experiences into goals for implementation within their classrooms. The data from both teacher and student interview transcripts, classroom observations, and workshop evaluations were coded and themes were formulated reflective of this study's research questions. Several codes that were identified included (a) teachers preconception of ISI; (b) teachers views on ISI as a result of the summer research; (c) implementation strategies to be utilized as a result of summer research; (d) beliefs about student learning; (e) development of content knowledge; (f) enactment of ISI within their classrooms; (g) instructional strategies utilized within classroom; and (h) the successes as well as barriers to implementation of ISI within the classroom. In addition, the research team collected and shared data from all the participants to develop case studies which exemplified a continuum of knowledge and implementation of ISI. This was derived from a detailed analysis and discussion on the degree to which teachers were tagged as having understood and implemented ISI. Through this inductive approach, the data analysis was completed on all sources of data by multiple researchers to ensure that the findings and emerging themes were valid.

Findings

Three teachers were selected for the purpose of this study. The pseudonyms utilized for the teachers are Jack, Chris, and Stash. Teachers' case studies are presented in the following two sections reflecting our findings. The first set of data informs us of teachers' understanding and development of ISI knowledge by answering the research question: How do science teachers' knowledge and understanding of ISI evolve as a result of university research and follow-up in-school support? Evidence for this question is derived from data such as proposals, teacher log sheets, poster presentations, evaluation of the PD workshops as well as teacher interviews.

The second section reflects implementation of a variety of ISI instructional strategies within the classroom setting; it aims at answering the second research question: How is a science teachers' knowledge of ISI demonstrated through their teaching strategies? The data that support this section are derived from classroom observations.

Teachers' Conceptions and Development of ISI Knowledge

Proposals Jack's proposal had a textbook definition and explanation of ISI. He stated the following in his summer research proposal.

> This research will benefit our students in many ways. First, hands –on learning will enhance student comprehension and inquiry based learning of the components of engineering structural designs. Second, research driven projects will enhance student reading and writing skills which is part of the fundamentals of cross curricular teacher development. Third, students will be exposed to how evolution is stimulated by catastrophic events in the environment.

Jack also explained his idea of ISI as something that tied in several sciences such as Earth science, Environmental studies and Biology. However, his understanding was limited as he was unable to see problem solving through the lens of the important characteristics needed to solve real-life problems as connected to students' lives.

Chris, another science teacher, planned to develop a classroom model of a sustainable system as evidenced by his proposal.

> Upon completion of the summer research project we will have a model built to scale that can support the growth of various vegetables and fish for food. The model will allow the students to construct the system then maintain it. The students will be able to choose types of vegetables and fish they wish to use. It is my goal to then construct a second model in the classroom that we can use for experimental purposes. With this model, students will be able to isolate, identify, predict then manipulate an independent variable, observing results, drawing conclusions and report on their findings.

Chris seemed to have a clear sense of what he hoped to accomplish and the proposal had elements of the ISI process as stated in his goals.

Stash, the third science teacher in the study wanted to, for his summer research, work at a local cancer institute so that he could better understand the role of the immune system and cancer. He intended to align this experience into the body systems, a unit he taught his students.

> This is a method of teaching in which a science concept is taught not only in Biology but across several other disciplines such as mathematics, English language arts, social studies and technology.

He stated that although the learning of the science concept and laboratory skills would primarily occur in the science classroom, other disciplines and related content would also be a component of the overall project.

Stash articulated his understanding of ISI connected to his summer work as well as across curricular subjects with an understanding of the need of these subjects to be incorporated into his student lessons. He demonstrated a comprehensive understanding of ISI.

Teachers' Summer Research Context Observations

All the teachers in this study situated themselves in various summer research experiences at the university and local sites working alongside engineers and scientists in order to develop an understanding as well as to experience ISI practices.

Jack worked with a team of teachers during the summer at a research university with professors in the Civil, Structural, and Environmental Engineering department who were very knowledgeable in content and engaged the teachers in learning and finding ways to apply this understanding within classroom situations. Jack was exposed to the research process that scientists conducted in the real world and had many opportunities to understand and view ISI as demonstrated by what the scientists did. Their work was aligned to Jack's proposal goals which was specifically about learning how to integrate a deep understanding of catastrophic events such as earthquakes within his classroom practices.

Chris involved himself with research within laboratories of scientists that analyzed water quality. He also spent time inquiring and learning about sustainability and put together an Aquaponics model for use in the classroom as stated in his research proposal.

Stash had indicated an interest in immunology with a focus on the interactions between disease and the immune system. His summer research was at a local cancer research institute. He spent his summer in research laboratories in which he observed scientists and laboratory technicians conduct cancer research. The laboratories were rich in technology, and the professionals working explained in detail the integration of technology to enhance cancer diagnosis and treatment. They also helped Stash link the work they conducted in the laboratory into lessons and projects which could be utilized within his classroom.

Teachers' Summer Log Sheets

Of the three teachers in this study, Jack turned in 4 log sheets; however, they were identical. In it, he reflected,

> I plan on using the visual map we have developed to show students first hand on how seismic waves can be used to determine the location of an epicenter of an earthquake. I also plan on discussing with my students how the information used by seismic waves can be used to engineer buildings and structures to protect people from harm.

Neither Chris nor Stash turned in any summer log sheets and lost an important opportunity to be reflective on the process of ISI and the ways in which they could translate their learning experiences within classroom practices. This may have been a beneficial process for them to engage in as it provided them an opportunity to think about implementation within the classroom. The teachers may have reflected in other ways; however, as part of this study, we relied on data from summer log sheets to demonstrate evidence of reflection.

Teachers' Summer Poster Session

As a summary to the research experienced during the summer, a symposium was held for teachers to share their experiences with one another. This offered an opportunity for teachers to present their summer research experiences and to share how they intended to implement ISI in the fall.

Jack and his group presented a poster on what they had explored during the summer. The goals were reflective of teacher-driven practices rather than student-centered practices. It was an attempt to directly utilize the labs they experienced within their classroom practices through demonstrations and through direct connections. There was no evidence of an understanding or development of ISI reflected through this poster. Chris' poster demonstrated his understanding of the elements of ISI and its potential application in his classroom more so than other teachers. Stash's poster summarized his summer research experiences in the various laboratory settings. Stash had indicated he needed help with the implementation process; it was not clear from his poster how and what he planned to do within his classroom.

Teacher Feedback from Ongoing Professional Development Workshops

Teachers were engaged in PD workshops that offered support throughout the school year to help with ISI implementation. Jack did not attend any teacher workshops and therefore missed an opportunity to develop his understanding and ideas for implementation. Chris attended two PD workshops during the year of the partnership. He attended the workshops on understanding ISI, and he felt he gained a great deal of knowledge about the national documents such as the Next Generation of Science Standards and the Common Core Standards and how they connected to his current teaching practices and goals of the partnership. Stash attended the PD workshops regularly. He participated and was actively engaged in the learning process. This exposure increased his understanding of ISI and knowledge of implementation strategies to be utilized within his classroom.

Teacher Interviews

Teachers were interviewed to share their purpose for teaching science, their conceptions of ISI as well as their beliefs on student learning. During Jack's interview, he shared his purpose for teaching science as well as what he believed his classroom should look like in terms of evidence for learning.

> I feel like it is a very important subject that one should know about, more than any other because every single thing comes from the Earth and I try to keep my classes knowledgeable and interactive. I teach kids the way I like to be taught not just plain lectures but videos and review as well.

In terms of what he wanted his students to learn, he stated that

> I expect them to know enough so they do well on the June exam according to the standards and curriculum. I also want them to start thinking on their own. I'm also going to look to have material presented to children in a way in which they will understand it more comprehensively.

There was a contradiction in what Jack wanted for his students and what he actually practiced as evidenced by his classroom observations made by the researcher. Jack shared many reasons why it was challenging for him to implement his summer research within his classroom practices, such as, not having equipment because it was too expensive and even if he did it was too complex for his students to understand and utilize.

During the interview with Chris, he explained that he had entered the teaching profession through a program that pulled individuals from STEM professions into teaching. Chris's career was not entirely in teaching. Chris shared that he had a good summer experience and that he achieved his goals in setting up a sustainable Aquaponics model.

> I feel as though my goal was to come up with scalable model, I believe I do have scalable model and I have it in my classroom and I am very satisfied, and then of course it is to have students getting involved.

Chris also demonstrated that he was utilizing his model with students within his teaching. While he made connections to his model, it was still at a low level of inquiry and ISI. For example, he wanted his students to do testing, but there was little mention of them constructing models and identifying issues they were interested in exploring. He made minor connections but was still missing the big picture as to how his research experiences with ISI translated into practices for students. Chris also mentioned the challenges he would face when trying to implement his summer research such as student abilities to conduct inquiry. This is a key piece in teacher implementation of ISI. Having strong ideas and beliefs about what students can or cannot accomplish seriously hindered student experiences of ISI.

Chris listed the requisites for student learning of ISI. When a teacher like Chris fundamentally believes that students cannot conduct high-level science, the opportunities are never presented to them. Although Chris had a good understanding of science inquiry and had plans to implement an integrated approach to learning, in practice, Chris retreated to low-level inquiry experiences for his students because he believed they needed certain prerequisites to conduct inquiry. Chris believed that students needed an understanding of the basics before ISI could be implemented. For example, he stated

> Because we're trying to do inquiry and we are running into these issues where you're trying to have a discussion about something like sewage and it's like the discussion is going nowhere and is getting ridiculous and when we back it up we realize that well wait a minute, do our students want to know what sewage is?

He also stated his beliefs about his student's abilities,

> Understanding that 80 %'s of my ninth graders are low-level readers, so you know, they come to us lacking in basics skills in being a student. They aren't good students. Our kids in the inner-city have a very limited frame of reference in urban settings.

During Stash's interview, I asked him what he liked about teaching and how it aligned with the partnership goals. He stated

> I focused more on you know what I enjoyed teaching which was more projects and more engineering and stuff that goes along with the grant and I have always done a balance between science and literacy. I really use as many resources for high school that I have time for and I have a lot of things that say oh that is cool, and I won't get around to it and you know but I feel technology has a big place in my room.

Stash demonstrated a good understanding of ISI and that it was valuable to teach students in that fashion. He clearly saw connections in his summer research and the ways in which he could connect it to his existing curriculum and practices. His proposal, summer experiences, and interview questions were aligned to the goals and understanding of the partnership.

Implementation of ISI Evidenced by Classroom Observations

Jack invited me in to watch a lesson that he felt exemplified and reflected his summer research experiences. During his classroom observation, Jack conducted a lesson on exam review. Most of Jack's lesson reflected a solicitation of facts, providing directions, redirecting and rephrasing what students would say to lead them to the correct answer.

Jack's lesson had no correlation to his summer research experiences nor was there evidence of ISI instructional practices in his classroom observation. Although his lesson was anchored within the discipline of Earth Science, it clearly did not demonstrate any ISI strategies. Jack had stated in his interview that he wanted his classes to be student-centered and have rich science learning experiences; however, it was clearly not the case from our observations.

Chris invited me in to observe his classroom. His lesson goals for the day were to review photosynthesis and cellular respiration, watch a video on Aquaponics and to have a discussion based on the sustainability model he had created for this classroom based on his summer research work. He utilized a KWL chart and had students fill out as a whole group. A KWL chart asks students to reveal what they already know, what they want to know, and what they have learned about a particular topic. Students then watched a video and discussed the concept of cycles and how systems sustain themselves utilizing the Aquaponics model. Chris elicited facts from students; he gave directions and corrected mistakes. He gave out information and students followed directions.

Chris's lesson did not reflect questioning on the part of students, and students did not design ways in which to investigate or research a problem. There was no evidence of data gathering nor were there any opportunities for students to interpret data and build arguments. Although Chris had displayed an interest in making the sustainability model a tool for inquiry, there was little evidence of inquiry in the classroom and little connection to his summer research. This is not surprising when we look at the beliefs Chris held about the role of students in his classroom and the requisites for learning as evidenced in his interviews.

> The challenges of implementing inquiry in a classroom are twofold. First, students must be motivated at least enough to have an interest in the inquiry question/problem/project. Second, students must have a minimal amount of

knowledge of the content or at least of the skills necessary to begin to conduct an inquiry-based investigation.

In Stash's classroom, he conducted a lesson on cancer and how to identify unknown cells for the possibility of disease. A complex computer program was simplified for students to make the analysis as they worked individually and collaboratively. Students utilized their understanding of cancer and how it related to their own lives and how it related to their understanding of the diagnosis of the disease. Stash's lesson involved some explanations and instruction given during the lesson. The lesson was situated well within a larger context of learning in the curriculum as well as connected to students' lives. Some redirection of students to focus was required, but there were opportunities for students to evaluate their work with reasoning and scenarios. There was evidence of encouragement to participate and come up with creative answers.

Stash utilized his summer research experience in the cancer laboratories and infused it within his curriculum. His instructional strategies reflected his understanding of ISI. His lesson was contextualized within the larger problem of cancer causes and diagnosis as well as a focus on prevention. It was relevant to students' lives as many have family members and friends who struggle with cancer. The lesson was anchored within the discipline of biology and also infused other disciplines such as chemistry, literacy, and technology. Stash's lesson was aligned with his summer research goals and implemented strategies that he had been exposed to through the summer learning experience as well as the PD workshops he attended.

A STEM graduate student was an instrumental and vital part of the planning and implementation of technology in Stash's classroom lesson. He fell under the umbrella of the larger professional learning community as many STEM students were at the disposal of teachers to be utilized as part of developing and implementing their knowledge of ISI. The STEM graduate students' understanding of complex data systems and computer programs assisted in planning the lesson reflecting how scientists diagnose and detect cancer in the real world. The carrying out of the lesson by undergraduate STEM students also assisted in implementation. With so many knowledgeable students in the room who had an opportunity to develop rapport and relationships with students, the lesson went particularly well.

Findings from Classroom Observations of ISI Implementation

To answer our research questions, Jack had many opportunities to develop ISI through the summer research experiences and in class PD support. As a result of not attending the PD workshops, Jack had a fragmented understanding of ISI and had little opportunity to connect his summer experiences into an application of instructional strategies that reflected ISI. Jack's knowledge and beliefs about his students were critical in identifying the barriers to successful implementation of ISI. Chris came in with a sound background in science content prior to the summer research experience and continued to develop his content knowledge. He utilized his summer experiences and demonstrated his understanding of ISI as exemplified by the sustainability model he created and the ways in which he planned implementation of this knowledge.

Chris developed both his content as well as knowledge of ISI. However, where he lacked was in implementation as he failed to demonstrate a good application of this knowledge through his pedagogical practices and instructional strategies. His beliefs about what his students could accomplish limited his application of ISI. Although he developed knowledge of ISI, he was unable to translate his experience and understanding through instructional strategies within his classroom.

Stash clearly demonstrated an interest in wanting to connect his summer research experience at the cancer institute to his classroom practices from the inception of his written proposal. Stash had many resources available to him such as his experience from the summer, STEM students in his classroom, his interest in his students, having access to equipment, as well as an understanding of methods and strategies related to ISI. Stash attended all supporting ISI workshops and with the help of the resources available to him, worked with his post doctorate STEM student, his cancer institute resources and the learning he acquired through his PD to create relevant learning experiences for his students. Stash developed in both science content and pedagogy. His in-depth understanding of his students and context allowed him to create a lesson that was exemplary in ISI characteristics.

Discussion

Reflecting on our findings, we conclude that teachers interacted with the partnership in different ways, therefore developing varied levels of ISI understanding and experiences. Teachers also exhibited varying levels of growth in both content and pedagogy. As a consequence, each teacher also varied in their application of ISI within their classrooms as evidenced by their choices of instructional practices. As a result of data analysis and findings, some major themes emerged.

Theme 1 Teachers' perceptions and conceptions of ISI were impacted over the course of the ISEP partnership.

A conclusion that can be drawn from the ISEP partnership was that the involvement in summer research and ongoing PD had an impact on the conceptions of teachers' ISI knowledge evolution. In their initial proposals, all teachers demonstrated a fragmented and varied understanding of ISI. These initial conceptions of ISI developed and changed as the teachers engrossed themselves in various research experiences at the university and research settings.

Theme 2 The summer university research experience and PD aided to varying degrees of teachers' interpretations of ISI.

Teachers experienced various ISI research experiences during the summer. Each teacher was located within a research setting of their choice and as a result experienced varied levels of ISI. Depending on how many in-service PD workshops teachers attended, teachers gained a better understanding and were able to implement ISI in their classrooms with greater alignment and success.

Theme 3 The varied interpretations of ISI impacted the way in which teachers implemented ISI instructional strategies within their classrooms.

The varied interpretations and understandings of ISI impacted the translation and implementation of ISI practices within each teacher's classroom. Jack's initial conceptions of ISI remained about the same as demonstrated by his instructional practices. His lack of ISI understanding was further complicated by his un-involvement in completing teacher logs, PD, and the views and beliefs he held about his students' abilities.

In Chris's lesson there was little evidence of ISI instructional strategies and practices. Although Chris understood science content and ISI, he was limited in his practices by the beliefs he held about his students' abilities and the requisites required to teach ISI.

Stash too had a fragmented understanding of ISI; however, due to his summer research and experiences and PD involvement, he was able to translate his knowledge into instructional practices in his classroom. His lesson exemplified the greatest characteristics of ISI as described in his classroom observations, and he demonstrated a sound contextual understanding of his students and environment.

Conclusion and Implications

In order to increase understanding and application of ISI, teacher PD must continually contribute to teachers' growth in knowledge of both science content and pedagogy. It also must take into consideration contextual and cultural factors of the schools and teachers within which it aims to create change.

As exemplified by the three teachers highlighted in this study, teacher conceptions and practice of ISI varied and progressed as a result of summer research and PD experiences. Variation in ISI understanding and practice was a result of the combination of teachers' experiences, beliefs, and participation. In order for successful understanding and implementation, it is imperative that all participants be fully accountable for engagement in all aspects of the study. If teacher development is to take place, all teachers must engage in the learning experiences provided to them. For example, filling out log sheets may have been a reflective process for teachers and would have helped them to bridge the connection from their research to classroom practice. Attending all PD sessions may have also aided teachers who may have struggled with translating their experiences into practices within their classrooms. Limited participation in some aspects of the partnership also affected the variability in teaching and learning outcomes for students.

Teachers in this study had little experience designing curriculum in the past, and there was some disconnect between what the grant developers aimed for and what the school district actually supported. There was also a mismatch as ISI and inquiry strategies in science were not a part of prescribed local, state, and national assessments in this study. Some teachers did not change their practices because some important contextual factors were not in place. As a result, although there was a professed agreement to learn and change practice, there was little evidence of enactment in the teachers in whom no growth was present. Our teachers may also have benefitted in an ongoing relationship between the experts and the classroom teacher throughout the year with support from the experts rather than only in the summer. Urban contexts also have a myriad of issues and challenges related to teaching and learning and factors must be taken into consideration.

Factors such as teacher beliefs about science, pedagogy, and learning must also be addressed to help shift the fundamental ideologies of teachers. Although teachers developed in both science content and ISI processes, teachers' PCK may not have developed (Friedrichsen, Driel, & Abell, 2011). Smith and Neale (1989) conclude that unless teachers have acquired a "deeply principled conceptual change in content knowledge, the development of PCK is unlikely to occur (p. 17)."

This research is worthwhile to help us answer the questions such as what measures are necessary to help teachers develop ISI knowledge and successfully implement that understanding within their educational contexts. Knowing that there are many challenges in PD aimed at teachers conducting science inquiry, it is imperative and critical for teachers to increase their understanding and practice in ISI methods that integrate STEM subjects. This can help teachers attain the goal of better educated and prepared citizens who are ready for a global understanding of the nature of scientific problem solving.

Appendix: Description of Professional Development Workshops

Workshop title	Professional development workshop agenda and area of focus
Workshop #1 Understanding ISI	Took an in-depth look at Next Generation of Science Standards (NGSS) and component of the National Common Core Standards (NCCC) and the K-12 framework and how it connects to ISI and Interdisciplinary Science and Engineering Partnership (ISEP)
	Shared scientists explanations and examples of ISI derived from interviews
	Teachers given cases to identify dimensions of ISI to make understanding more explicit
	Teachers given an opportunity to discuss how other disciplines can enhance understanding of discipline content knowledge
	Explanation of pedagogical content knowledge (PCK) framework and the transforming of summer research experiences into classroom lesson linked to student achievement

Workshop title	Professional development workshop agenda and area of focus
Workshop #2	Explanation and expectations of partnership and the role of the research team as well as topics of PD sessions for the school year. Specific data collection methods and expectations shared with teachers as well as the role of the research team in data collection and reporting
Professional learning communities and the role of the Research Team in the process of ISEP partnership	Role of STEM students in teachers support as well as understanding and implementation of ISI
	Reviewing the ISI framework
	Videos of science scenarios and identification of ISI. Teachers identified aspects of ISI and created maps of their video observations to be shared with the group
	Exemplary examples of how teachers have collaborated with partners in the ISEP professional learning communities (PLC)
Workshop #3 and #4	Teachers given ISI teaching rubric and explored how to rate it
ISI teaching strategies	Teachers engaged in a lesson with specific roles to go through an ISI investigation on the topic of cell phones and cancer
	Evaluated ISI lesson through rubric and discussed establishing a common language
	Teachers identified lesson to revise using ISI, made specific connections to ISI experiences for their students and shared and received peer feedback
	Teachers visited the local museum and visited exhibits
	Defined project-based science and ISI overlaps
	Discussed instructional strategies supporting PBS such as concept maps, 5E model
	Reiterated dimensions of ISI to explain framework
	Teachers discuss how exhibits at the museum could be utilized to design PBS units with ISI features embedded within it connecting it to their summer research experiences
	Provided examples of PBS units on topics such as the effect of solid waste and its effect on a community and identifying ISI components

Workshop title	Professional development workshop agenda and area of focus
Workshop #5 NGSS and Common Core and ISI teaching strategies continued	Helping teachers understand the impact of teacher knowledge of standards and its impact on curricular decisions Teachers completed survey on their understanding of implementing of NGSS, ISI and NCCC and reviewed Teachers connected their current implementation of NCCC standards to the ISI framework Teachers discuss what their needs are related to implementation such as school requirements, equipment and resources Teachers create a unit/lesson they can utilize in their classrooms integrating current standards as well as ISI framework Teachers engage in peer contributions on how other disciplines can be integrated into their science lessons and groups share their lesson plans with other participants
Workshop #6 Teacher exemplars of ISI lessons	Teachers were provided Summer Research and Implementation exemplars of colleagues that were engaged in ISI in a quality way. The summaries were prepared by the research team and included a description of the summer research, implementation strategies, role of STEM students as well as parent outreach in some cases. Examples from the first year of ISEP teacher projects were shared. STEM students also shared experiences on how they contributed to teacher understanding of ISI and implementation of ISI
Workshop #7 Assessing ISI	Teachers engaged in a review of the ISI conceptual framework and participated in an ISI investigation called Maintaining water systems. They developed a scoring rubric for ISI learning and applying the ISI rubric to this particular investigation. Groups shared scoring rubrics to agree and come to consensus on important elements of the ISI Framework. Discussion includes advantages and challenges to assessing ISI

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