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

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Abstract

Developing Interdisciplinary Science Inquiry knowledge and practices help teachers improve both science instruction and student learning. The current literature supports how teachers develop knowledge and practice of science inquiry but little has been reported on how teachers develop interdisciplinary science inquiry knowledge (ISI). Implementing ISI is new for teachers and requires support. This study examines the effect of university research experiences, ongoing professional development and in school support on teachers' development of ISI. The resulting instructional practices of teachers should be reflective of ISI characteristics. Since teachers are involved in the development of the knowledge of both science content and instructional strategies their resulting Pedagogical Content Knowledge should also evolve. Barriers to ISI knowledge development and implementation, such as program alignment, teacher needs and teachers' attitudes and beliefs towards their students, science and pedagogy must also be addressed.

Introduction

National reform movement's today aim to enhance scientific literacy in students by developing their scientific understanding, higher order thinking and problem-solving skills. According to the National Science Education standards, science education should help develop students' skills for using science to solve problems (NRC 2000). This learning is accomplished by encouraging and training teachers to use student centered science inquiry methods in which students can construct new knowledge. Inquiry is an approach that involves students in problem-solving experiences in which they discover meaning through their investigations. Science Inquiry is identified as both content for students to learn, and an approach to reforming science instruction (NRC 1996, 2000). Inquiry learning challenges students by requiring them to collaborate with peers, construct usable knowledge by linking new and old ideas, relate new science content to their lives in and outside of school, and self-regulate across the weeks that an inquiry project might unfold (Blumenfeld et al., 1991; Krajcik et al., 1998).

However teaching inquiry-driven science is complex and science teachers typically have a poor understanding of inquiry, and are unable to implement inquiry science teaching in their science classrooms (Roehrig & Luft, 2004a & b;Wallace & Kang, 2004; Windschitl, 2004). The National Research Council Committee notes, *"Most teachers have not had opportunities to learn science inquiry or to conduct science inquiry themselves. Nor do many teachers have the understanding and skills they need to use inquiry thoughtfully and appropriately in their classrooms (p. 87)"* (NRC, 2000). Because teachers lack knowledge on science inquiry the quality of current high school experiences of inquiry is poor for most students (NRC 2006).

The National Science Education Standards (NRC, 1996) recommend that professional development 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'. Characteristics for successful professional development included deep science content and process knowledge with numerous opportunities for practice, the requirement that teachers demonstrate competence in a tangible and accessible way, and high expectations for learning and capability for them to facilitate multifaceted inquiry experiences with their students. Professional development must continue to increase teachers' content as well as pedagogical knowledge through rich learning experiences.

Professional development programs that are devoted to school practice have a greater likelihood of successful implementation (Cohen 2005; Waslander 2007). Professional development (PD) must be linked to what teachers' every-day practices within their classrooms and be run by professionals who are experienced in both the domain of the science as well as in teaching. Active teacher participation influences the quality of lessons teachers create and is linked to student achievement (Fishman et al. 2003). Professional development as a part of teacher development involves not only the use of different teaching activities but also the development of teacher beliefs and conceptions of those activities as suggested by Supovitz and Turner (2000) who studied the effects of PD on science teachers' practices and classroom culture.

The need for professional development of teachers in inquiry methods is further highlighted by the recommendations made by the National Research Council of the National Academy of Sciences (2012). It has released the draft form of the Next Generation of Science Standards document which elaborates on the idea of interdisciplinary science inquiry. Interdisciplinary

Science Inquiry calls for an integrated approach to teaching science with technology, mathematics and engineering practices and relevance to students' lives. Interdisciplinary Science Inquiry is both the application of science content and pedagogy. We define ISI in terms of the following characteristics.

- A Contextualized nature of problems which establishes relevance to students' lives
- Incorporates Inquiry and engineering process skills or practices to learn science
- Creates connection within and across disciplines such as Mathematics, English Language Arts, Engineering, and Science.
- Anchored within specific science disciplines (Nargund-Joshi & Liu, 2013).

While there is a body of literature on how teachers develop knowledge of and practice science inquiry in the classroom, little research has been reported on how teachers develop knowledge of and practice interdisciplinary science inquiry. The purpose of this study is to examine the evolution of teachers' interdisciplinary science inquiry knowledge and resulting instructional practices. 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 and through participation in professional development during the school year. Because teachers are engaged in the development of both science content and in the knowledge of instructional strategies, their Pedagogical Content Knowledge (PCK) should also evolve through the partnership. This study aims to answer the following questions.

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

One of the main goals of the Interdisciplinary Science and Engineering Partnership is to improve science teachers' content knowledge and skills in conducting ISI. The research questions in this study serve to inform us on the process of teacher knowledge development, specifically ISI and its resulting practice. Teachers gain new knowledge of ISI through university research experiences and ongoing professional development through which teachers increase their science content as well as knowledge of instructional strategies. This understanding of ISI is translated into their PCK which is reflected in the use of teachers' instructional strategies within the classroom. This improved knowledge and development of ISI practices are linked to student learning.

Literature Review

There is significant research on teacher professional development and the impact of professional development on teachers' classroom teaching practices. The National Academy of Education's (NAE) Preparing Teachers for a Changing World (2005) and Studying Teacher Education: The Report of the AERA Panel on Research and Teacher Education (Cochran-Smith & Zeichner, 2005) offer comprehensive, research-based analyses regarding the teacher education knowledge base. The NAE report focuses on the curriculum of teacher education. The report describes eight domains that should be included in teacher education programs: learning, development, language, social contexts and purposes of education, content knowledge and pedagogy, teaching diverse learners, assessment, and classroom management (Dorsch 2006).

A study by Crawford (2000) focuses on characteristics needed to teach science inquiry. They include creating real-world research activities, modeling the behavior of professional scientists, allowing students to collect and analyze real world data and professional development is a means through which teachers get experiences in learning and teaching inquiry. Working alongside scientists during summer research programs enhance teachers'' skills and stimulate greater intellectual rigor (Odom 2001). Partnerships with scientists were a direct outgrowth of the summer research experiences. This was intended to strengthen teachers' knowledge and skills in conducting scientific research. As teachers worked in the field, many details about scientific methods and concepts were conferred to them by participating scientists (Dresner & Worley 2006). Professional development should be sustained over a long time span and since teacher practices change slowly over time, sufficient time, resources, and support are required to change and sustain teacher practices within the classroom. The most promising forms of professional development communicate a view of teachers not only as classroom experts, but also as productive and responsible members of a broader professional community and as persons embarked on a career that may span 30 years or more (Little 1993). The teacher educator must model inquiry for the teachers, and engage them in concrete teaching tasks, based on their classroom experience. (Zech et al. 2000) also emphasized collaborative inquiry where content knowledge could be developed through the investigation of problems that originated in the classroom.

(Singer et al.'s 2011) study focuses on literature surrounding professional development that emphasizes immersing teachers in inquiry, questioning, and experimentation. There should be intensive and sustained support in engaging teachers in concrete teaching tasks that integrate teachers' experiences. There should also be a focus on subject-matter knowledge and deepening teacher content knowledge. Teachers should be provided with explicit connections between the professional development activities and student outcome goals and connections to larger issues of education/school reforms. (Singer et al., 2011) utilized the Reformed Teaching Observation Protocol (RTOP) in their study to analyze the effectiveness of transference of Inquiry teaching strategies that teachers have gained through professional development activities focused on experiences and outcomes that included sustained activities that integrated content understanding, active learning, and coherence. ''Active learning'' refers to providing teachers with opportunities to apply the substance of the professional development activity via meaningful discussion, planning, and classroom utilization. ''Coherence'' refers to forming a unified set of opportunities for teacher learning and professional growth. The study showed significant improvement in teachers' ability to apply inquiry-based pedagogy.

Since this study lies within an urban context, it is important to recognize and take account the challenges that urban schools face. One of the biggest differences between urban schools and their counterparts in more affluent areas are the common means they have to implement science instruction, most often referred to as resources (Anderson, 2002; Johnson, 2006). In order for students to experience "doing" science, teachers must have curriculum, equipment, and consumables required to teach their content— and more often than not urban teachers are also mired in climates of low morale and low expectations (Anderson, 2002; Anyon, 2001; Johnson, 2006; Kozol, 2005). Some of the key components of professional development that have been highlighted in multiple studies include the following: engaging teachers in the context of their own classroom, strengthening content and pedagogical knowledge, providing opportunities for collaboration, and including experiences that engage teachers as learners (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003; Putnam & Borko, 1997). In addition, barriers to teacher change have also been addressed, such as lack of materials and curriculum, lack of district and school level support, lack of time for planning and collaboration, increasing accountability demands, and existing teacher beliefs regarding instructional strategies and support for change (Anderson & Helms, 2001; Johnson, 2006; Johnson, 2007b).

Keeping in mind the culture of the school environment is also a critical piece to successful professional development. (vanDriel et. al, 2001), discuss a top down approach to reform movements which often lead to failure of successful implementation by teachers because the developers assume to know how teachers can change their classroom behaviors. This approach often leads to a lack of success 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 professional development of science teachers as is seen in many programs and initiatives (Munby, Cunningham, & Lock, 2000).

The success of professional development programs is also affected largely by the beliefs that teachers hold onto about student learning. There is a need to consider that educational reform efforts are at risk of failure, if the focus is on developing specific teaching skills, unless the teachers’ beliefs, intentions, and attitudes, are taken into account (Haney, Czerniak, & Lumpe, 1996). Research about teacher beliefs demonstrates that although professional development interventions can support and enhance teachers’ learning of science, deeply rooted beliefs about science and the nature of science is often unaffected by institute involvement (Yerrick, Parke, & Nugent 1997). Therefore, professional development programs must keep in consideration 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; Luft 2001).

Keeping in mind the challenges that arise as changes in teacher practices are implemented, there are also effective outcomes of professional development. Longitudinal studies have emerged, which have linked sustained increases in student learning of science for teachers who have participated in science teacher professional development (Johnson, et. al, 2007a; Ruby, 2006). Professional development models have continued to evolve to include many critical components that lead teachers to change their practice and to better facilitate learning (Bell & Gilbert, 1996, Fishman et al., 2003; Loucks Horsley et al., 2003).

Theoretical Framework

The theoretical framework that informs this study is Pedagogical Content Knowledge (PCK) (Shulman, 1986, 1987). Student learning of science depends on teachers having adequate knowledge of science. The person who presumes to teach subject matter to children must demonstrate knowledge of that subject matter as a prerequisite to teaching (Shulman 1986). Shulman describes this specialized type of teacher knowledge as being the most regularly taught topics in one’s subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that make comprehensible to others..[it] also includes an understanding of what makes the learning of a specific topics easy or difficult (Shulman 1986)..

The PCK framework has demonstrated that a science teacher’s knowledge of their content is not enough to teach their subject matter. Teachers have to have knowledge of the various aspects of PCK such as knowledge of curriculum, knowledge of learners, assessment and instructional strategies (Magnusson, Krajcik, & Borko, 1999). This study aims to investigate how science teachers develop both knowledge of science content and instructional strategies and translate that into resulting pedagogical practices within their classrooms reflecting ISI.

Knowledge of instructional strategies has been most frequently referred to in the literature as a main component of PCK (Magnusson et al. 1999; Shulman 1987; Tamir 1988). Knowledge of instructional strategies includes subject-specific strategies and topic-specific strategies (Magnusson et al. 1999; Park & Oliver 2008). As its name implies, the term topic-specific strategy applies to any method by which the teacher focuses on a specific topic within a larger domain of science, such as models, analogies, and demonstrations. Subject-specific strategies refer to general strategies that are broadly applicable to science teaching such as inquiry-oriented instruction, learning cycles, and conceptual change strategies (Seung, Bryan & Haugan 2012).

The idea that teachers are the most influential factor in educational change is not controversial (Duffee & Aikenhead, 1992). It has been shown that the classroom teacher is the most important factor in student achievement (Friedrichsen, Abell, Pareja, Brown, Lankford & Volkman 2009). The strongest predictor of how well a state's students performed on a recent national assessment was the percentage of well-qualified teachers-those who were fully certified and majored in the subjects they taught (Friedrichsen et al., 2009).

This study focuses on the development of teachers' science content knowledge as well as knowledge of instructional strategies both of which influence PCK development. The PCK framework informs this study and provides a roadmap into the construction of new knowledge and whether this new knowledge transfers into pedagogical practices. It also sheds light on why successful implementation does or does not occur. Both the knowledge of students and the context influence a teachers' ability to transfer their content knowledge into pedagogical practices.

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 (Glesner 2006). The case study inquiry relies on multiple sources of evidence, with data needing to converge in a triangulating fashion (Yin, 1995).

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 explanation of direct interpretation. In this interpretation the researcher pulls data apart and puts them back together (2007). We then looked at possible themes that were formed as a result of initial analysis and tried to find connections or contradictions in the data (Seidman, 2006).

Context

A National Science Foundation 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 sought to establish a comprehensive interdisciplinary science and engineering partnership between the two partners with the primary goal to integrate the latest interdisciplinary science and engineering research approaches in science teaching by providing teachers with professional development and research experiences. The ISEP goals focus on developing teacher's interdisciplinary science inquiry knowledge and practices. These goals are targeted by providing teachers' opportunities to professionally develop their knowledge and skills of ISI through summer research experiences and ongoing professional development. Professional learning communities which support continuous growth and development of a teacher's interdisciplinary science inquiry knowledge and help in development of PCK specific to ISI are also an integral part of this project. Support from the university, graduate and undergraduate STEM students, the university's education researchers, the community and school district all encompass this project's goals to support the development of ISI.

The context of this partnership was the university setting and its various science and engineering departments and research laboratories that were involved through the grant. In addition, many local medical, engineering and research institutes as well as industrial partner sites were involved. Teachers were afforded the opportunity to work alongside scientists and professionals from science and engineering fields. The length of this partnership is over five years but the study reported in this paper focused on years one and two of the grant and its findings. The summer research experiences along with the professional development sessions were the focus of this particular study.

Science teachers involved in the partnership participated in summer research experiences in which they worked alongside scientists and professionals. They engaged in scientific research reflecting interdisciplinary science inquiry. In addition to the summer research experience, teachers were offered professional development workshops monthly, with each session being offered twice in order to maximize attendance. The duration of the workshops were three hours and were held at various locations such as the schools participating in the grant, the university and the local science museum. The science education research team conducted these workshops on various topics to assist teachers in further understanding of ISI and to support implementation of interdisciplinary science inquiry strategies. The topics of the workshop included understanding interdisciplinary inquiry; understanding the role of the professional learning communities that the teachers were involved in; evaluating interdisciplinary science inquiry; project based science framework and applications within ISI and focusing on the Next Generation of Science Standards, Interdisciplinary Science Inquiry 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 them into classroom instructional strategies and lessons.

Participants

For the purpose of this research study, we report data from three secondary-in service science teachers who participated in the ISEP grant. They were from an urban school district in the Northeastern region of the United States. The teachers serviced students from lower SES and racially diverse schools within the district. These schools were particularly challenging for students and teachers both socially and academically. Once enrolled in the grant these teachers participated through the variety of experiences aimed at increasing their knowledge, understanding and practice of interdisciplinary science inquiry. These participants were selected to reflect a sample of the continuum of varied experiences and implementation of ISI in the ISEP partnership. Summarized in Table 1 is background information on the three participants. Pseudonyms are utilized for the names of the participants.

Table 1- Background Information of Participant Teachers

Name	Gender	Race	Type of School	1rst and 2nd Profession	Subject Taught	Number of Years Teaching
Jack	Male	White	High School	1. Welder 2. Science Teacher (State Certified)	Environmental and Earth Science	
Chris	Male	White	High School	1. Criminal Justice 2. Science Teacher (Non-Traditional State Certification)	Living Environment (Biology)	11 Years
Stash	Male	White	Middle School	1. Science Teacher (State Certified)	Integrated Science	12 Years

Data Collection

Multiple sources of data were utilized, including written questionnaires from teachers focusing on their pre-conceptions of ISI, their summer proposals for entrance into the partnership, summer observations, log sheets, summary of summer research posters and classroom observations. Semi-structured interviews with teachers and students were also conducted. Ongoing professional development workshops also provided us feedback from teachers' through workshop evaluations and were utilized as a source of data. The use of a variety of data sources provided a rich resource for triangulation of data. In Ely's book, "Doing Qualitative Research Circle within Circles" (2006), the authors discuss triangulation. Many experts indicate that triangulation characteristically depends on the convergence of data gathered by different methods, such as observations and interview. Guba and Lincoln (1989) suggest that researchers seek only to triangulate, to cross check specific data and presentation with the people they studies and with their peer support group. 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. Triangulation can be of data sources, among different evaluators, perspectives on the same data set and triangulation of methods (Yin 1995). The examination of the evidence from different perspectives will increase the chances that a case study will be exemplary (Yin, 1995). A chain of evidence demonstrates to us that the researchers attended to the validity of the study (Yin 1995).

Data collection began with teachers' initial conceptions of ISI demonstrated through a questionnaire as well as their original written proposals. This data provided us with teachers' initial understandings of ISI and the challenges and benefits they viewed when teaching in this fashion.

Once teachers were accepted into the grant, data was collected during their summer research experiences in the form of daily log sheets which served as a means for teachers to reflect on how their experiences aligned with ISI characteristics and the way in which they could link this experience to their instructional practices. The format of the log sheets asked teachers to reflect on how the science and engineering practices as well as crosscutting concepts related to their experience during the summer research. Log sheets were analyzed and summarized for each participant to see the progress teachers made in their understanding and connection to ISI practices. Participant observation of their summer research was conducted and data was collected through audio and video recordings. These audio and video recordings were transcribed and pseudonyms were used for the participants. This data provided us with details of what experiences teachers had in the summer and how well it reflected ISI. Because there was a degree of variation in the teachers' summer research experiences it was influential in the experience, understanding and implementation of ISI for each teacher. Since ISI was not explicitly stated in the summer experiences it was the teacher's interpretations and understanding that influenced how they implemented their knowledge through instructional strategies within their classrooms. At the end of the summer teachers participated in presenting posters that reflected their overall summer research and explained how it would be implemented within their classroom experiences.

Teachers' classroom observations were made utilizing a standard observation data collection instrument protocol. The protocol included a classroom observation sheet which focused on events during the lesson and the method in which the teacher conducted the lesson. It focused on details on the level of questioning, the quality of feedback as well and gauging student thinking by the teacher to their students. The events were coded by the nature of verbal as well as physical activities that were conducted in the lesson. The protocol also focused on levels of engagement by students during the lesson. Once the data was collected during the lesson, we followed up with a post observation coding rubric for investigation related experiences, instructional leadership practices and for science content for both middle and high school teachers. Identification of ISI characteristics were a focal point during the classroom observations. The ISI characteristics that we sought out were to see if the lesson was contextualized and if it established relevance to students' lives. We also sought to see if Inquiry process skills or practices were embedded within the lesson. We looked to see if the lesson created connections within and across disciplines as well as being anchored within the science discipline of that class. The classroom observations were audio and video recorded, transcribed and analyzed for the identification of characteristics highlighted by the protocol. Classroom artifacts such as student work and teacher lessons were collected. We sought to see if teachers made clear connections to their summer research experiences and if their instructional strategies reflected ISI.

Semi-structured teacher and student interviews were audio recorded and transcribed. These interviews provided us with rich data on teachers' conceptions of ISI and how they implemented their research experiences. The interviews also provided us with data on the challenges and celebrations teachers' faced when they conducted their lessons. Student interviews provided us data on what students wanted to learn in science that connected to their lives and their communities. Teachers were asked if they would teach science explicitly for kids and we gathered data on teachers' views, beliefs and attitudes towards teaching science by the responses they provided based on their students' interviews. Teachers' conceptions, beliefs and attitudes about science teaching and students' abilities provided insight into the variation of ISI implementation within classrooms. Provided below is a timeline of data collection of year one and two of the ISEP grant.

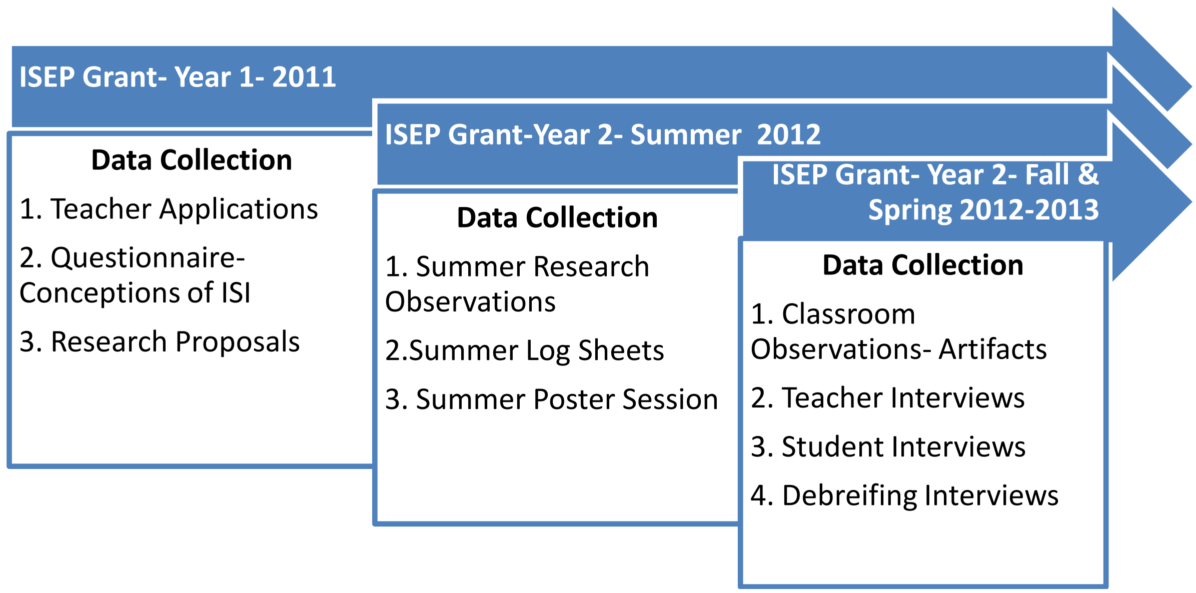


Table 2 provides a summary of the data collected.

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, cross cutting concepts and also included an area for personal written reflections which asked them if 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 expected to create posters representing a summary of what they did. These posters were presented and shared during a poster presentation event. The posters ranged and varied in what the participants presented
Evaluations of Professional Development Workshops	Teachers were also given the opportunity to engage in ongoing monthly professional development 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 Interdisciplinary

	Science Inquiry strategies in their classrooms. The topics of the workshop included Understanding Interdisciplinary Inquiry; Understanding the role of the Professional Learning Communities that the teachers were involved in; Evaluating Interdisciplinary Science Inquiry; Project Based Science Framework and applications within ISI and Focusing on the Next Generation of Science Standards, Interdisciplinary Science Inquiry 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.
Teacher Interviews	Teacher interviews informed us on the history of each teacher participants experience with science education and their preparation. It focused on their approach and purpose to teaching science. It asked their expectations for student learning and how they planned to change their instruction reflective of ISI as a result of their summer research experiences and professional development. They were asked how they modified their curriculum in light of new knowledge and provide examples of the challenges and celebrations they experiences as a result of implementing the summer research and ISI strategies into their teaching practices.
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 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. Each of the three teachers demonstrated varying levels of development in each of the three categories.
Student Interviews	Student interviews informed us on what students interests were in science and focused on the content and methods in which they wanted to learn science within their classrooms.
Debriefing of Student Interviews with Teachers	The data from student interviews was used to debrief with teachers focusing on their responses as to whether they would teach science explicitly for students and if not then providing reasons for why they couldn't or wouldn't.

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 explanation of direct interpretation. In this interpretation the researcher pulls data apart and puts them back together (2007). We then looked at possible themes that were formed as a result of initial analysis and tried to find connections or contradictions in the data (Seidman, 2006).

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. Some of the codes identified were teachers preconception of ISI, their views on ISI as a result of the summer research, implementation strategies to be utilized as a result of summer research, their beliefs about their students learning, their development of content knowledge, how they enacted ISI within their classrooms, the reasoning for the instructional strategies they utilized and the successes, challenges and barriers to implementation of ISI within their classrooms.

Findings

Among the participants within my cohort, a sample of three teachers were selected for this study with each displaying various levels of understanding and implementation of ISI along a continuum from novice to exemplary. Their understanding and implementation of ISI strategies was evidenced by the variety of data sources we selected.

The participants selected included Jack, a white high school teacher teaching Earth science to 9th and 10th graders in a low performing school, Stash another white teacher teaching in a low performing urban middle school teaching science to 7th and 8th graders and Chris, a white high school teachers teaching integrated science to 9th and 10th graders. Each teacher had varied experiences during the summer as described below. As the data was analyzed through the ISEP intervention, we searched to see how teachers' knowledge and understanding of ISI changed as a result of the university research and follow up in school support. We also looked specifically at the types of instructional strategies the teachers' utilized within their classrooms reflecting their understanding of ISI.

Each teacher's case study is presented in two sections which reflect my research questions. The first set of data informs us of a teachers' understanding and development of ISI knowledge by answering my first research question: (a) How do science teachers' knowledge and understanding of ISI evolve as a result of university research and follow-up in school support?
The data that informs this section is derived from proposals, teacher log sheets, poster presentations, evaluation of the professional development workshops as well as teacher interviews.

The second section of each case study reflects the implementation of a variety of ISI instructional strategies within the classroom setting aimed at answering my second research question: (b) How is a science teachers' knowledge of ISI demonstrated through their teaching strategies? The data that supports this section comes from classroom observations, student interviews as well as the debriefing of the student interviews with teachers. The data sources utilized and their purpose is summarized in the table below.

Graphical representations in the case studies of teachers understanding of science, pedagogy and learning are gathered from the following resources.

a. Understanding of Science- is concluded by data collected in their summer logs, summer research, classroom observations as well as interviews.
b. Understanding of pedagogy- is concluded from data collected during classroom observations in the standard observation protocol as well as the debriefing of student interviews.
c. Understanding of learning- is concluded from classroom lessons, classroom observations, student interviews and their debriefings.

Case Study #1: Jack

Conceptions and Development of Interdisciplinary Science Inquiry Knowledge

Proposal:

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. Finally, students will gain higher comprehension in regards to the effects of humans on the environment. This research enhances our interdisciplinary science inquiry at the secondary school level through several sciences including: Earth Science, Environmental Science and Living Environment."

From this statement we would expect to find evidence of this in Jack's classroom practices.

Summer Research Context Observations:

Jack worked with a team of 3 teachers during the summer at a research university with professors in the Civil and Structural and Environmental Engineering Department. He worked with structural monitoring and the Transportations Systems Engineering areas. The majority of his time was spent with the graduate students of the scientists. They 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. I was a participant observer throughout Jack's summer research experiences in the various laboratory settings at the university. From what I observed Jack had many opportunities to understand and see ISI as demonstrated by what the scientists did.

Summer Log Sheets:

Jack did turn 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."
>
> There is little evidence from this statement of Jack's development of ISI and its practice. The instructional strategies that he intends on utilizing are supported by traditional instruction and have little to do with inquiry. They also are in contradiction to what he stated in his research proposal.

Summer Poster Session:

Jack and his group presented a poster with what they had explored during the summer. In a section labeled, Classroom Application of Research, Jack and his group listed the following as their goals. (a)"**Triangulation:** Our experience will be used in doing a demo and hands on experiment where students will find out where three seismograph stations are located, given a known epicenter. (b)**Emergency Evacuation**: Given a map students will design their own emergency evacuation routes taking into account traffic and signal patterns. (c)**Mass Movement**: teacher will use Abaqus simulation model to demo different mass movements that caused structural damage."

These classroom goals are reflective of teacher-driven practices rather than student-centered practices as would be expected in conducting inquiry. It was an attempt to directly utilize the labs they experienced within their classroom practices through demonstrations and through direct connections. There is no evidence of ISI understanding or development reflected through this poster.

Ongoing Professional Development Workshop Evaluations:

Jack did not attend any teacher workshops and therefore missed an opportunity to develop his understanding and ideas for implementation. He gained little knowledge on the use of ISI instructional strategies that could have helped his implementation as a result of his absence in the workshops.

Teacher Interview:

During Jack's interview he shared his purpose for teaching science as well as what he believed his classroom should look like. He explained what learning looked like in his classroom by describing what students would be doing.

> "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 lecturers but videos lecturers 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. It means showing a video and then breaking the video but down about what they were talking about and if it means doing hands-on projects were they're going to walk around the school and take different figuring out dew point relative humidity."

There is a contradiction in what Jack wants for his students and what he actually practices. During his summer research experience Jack stated that,

> "That was my what I really wanted to do was actually give the kids a hands-on labs my having them build structures and then apply the principles of earthquakes to those structures and see if they can with holds and withstand that type of impact for force but I was a little dissatisfied with what we did because I thought we could do a lot more and I wasn't because our team wasn't trying because we were. We did we were committed but we just kept on running into walls and it was very aggravating. I would love to say it worked but I have the steel plate but I don't have any of the sensors the oscilloscope is expensive and kids wouldn't really get a good idea of what is going on with the oscilloscope. It's too complex for them." Jack shared his ideas as to why the summer research was challenging and could not work in his classroom.

Jack has illustrated through his ideas above, that even though he had a plan of action as stated in his proposal, he began to interpret his summer research experiences with stumbling blocks and interpretations that were clearly not helping him develop ISI knowledge. This leads us into Jack's classroom which although stated in his proposal that student learning would be the focus through good science practices, we see that there is little evidence of that in this lesson.

Implementing Interdisciplinary Science Inquiry Strategies demonstrated by Instructional Strategies

Classroom Observations:

Jack invited me in to watch a lesson that he felt exemplified and reflected his summer research experiences. During the classroom observation Jack conducted a lesson on Regents Review. He stood in the front of the room and utilized the Smart board to project questions on past regents exams. He put forth a timer and allotted a certain time in which students who informally sat in groups and stood around the bench were asked to answer the multiple choice questions. Jack and his students had informal conversations and he managed to keep most of the students partially focused and engaged in an informal review session. 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.

Most of the work done was individual and engagement was compromised. Jack's lesson had no correlation to his summer research experiences. There was no evidence of ISI instructional practices in his classroom observation. There was no contextualized nature of problem solving, nor was there evidence of establishing relevance to students' lives in the lesson he conducted. There were no inquiry process skills or practices nor were there any connections within and across disciplines. His lesson was anchored within his science discipline of Earth Science but it clearly did not demonstrate any ISI strategies.

Although Jack had stated in his interview that he wanted his classes to be student centered and have rich science learning experiences that was clearly not the case from our observations. Jack's claims to student learning were further challenged by interviews with his students. The interviews provided Jack an opportunity to articulate if he would teach science explicitly for his students based on their interests.

Student Interviews:

I interviewed Jack's students and asked them questions such as, what topics they liked in science and if given the opportunity to learn about any local topic of interest in their classes what they would be interested in researching? The students responded with

> "I want to learn about software engineering, local water pollution and life on other planets." Another student said he wanted to learn about computer programming because, "I like to play video games and want to create them one day", and another commented that she wanted to explore life on other planets because "People will have someplace to go one day when the Earth is too polluted" and another student inquired about learning about water pollution because we, "live near the Great lakes and it affects the life in and out of the water."

Students said they found interest in these topics because if affected them and interested them. The students and I discussed the nature of research and what sorts of tools and ideas we would need to conduct the areas of research they were interested in learning about. We came to the conclusion that they needed knowledgeable people like scientists to help and tools such as ways to compute and analyze data and most importantly that this learning had to be conducted in the field and with real data.

Debriefing of Student Interviews with teachers:

At the conclusion of student interviews I debriefed the student responses with Jack. I questioned if he was aware of these local problems in the area and if he would be willing to teach these topics explicitly for students within his classroom? His response was,

> "absolutely, the only problem is it is not in the curriculum and that would be an awesome thing to do, but I don't have the time, with all the curriculum and everything else to cover, I don't have the time and we don't have the resources either. We would need bussing, to feed the kids, and it would have to be put in the schedule."

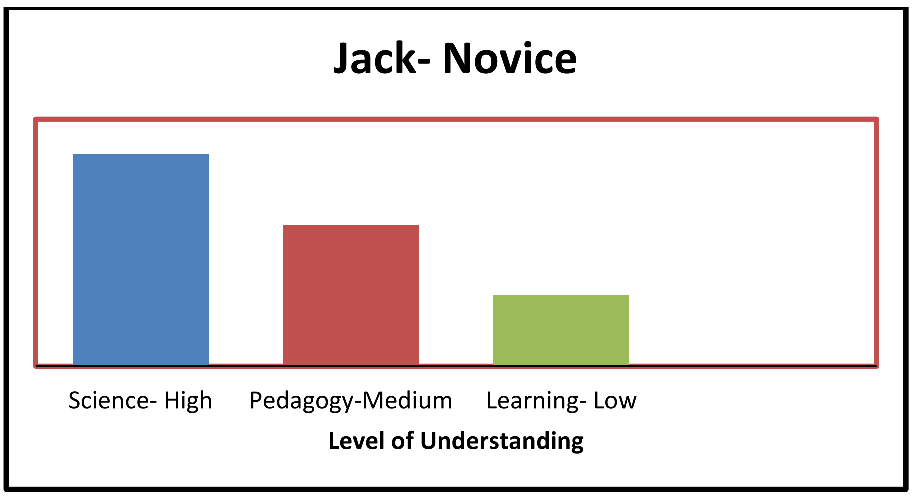
Jack also commented on how he was already behind in his pacing guide as compared to his colleagues because, "I look at the Regents questions that the students miss and teach and reteach it rather than waiting till the end of the year to review". When I asked if that worked for the students that were struggling, his response was "no it is constant review." So I asked him if there was value in students conducting project based learning and doing something a little off the curriculum path and he concluded that, " since students come in with varied interests and socioeconomic status and don't like being fed information and have them regurgitate it, "there should be a vocational path for them to consider or follow." Jack also said had he the time he would have considered having students work with computers and software to create simulations of Earth Science related topics in the classroom.

Summary of Jack's findings:

Based on the data collected and analyzed above Jack did experience a good deal of exposure to science content during his summer experience; however he was unable to translate that into practice into his classroom. His pedagogical practices did not demonstrate any application of ISI. He was not influenced by the interaction and summer research with the scientists and could not connect to the experience as related to his classroom practices. Jack had the experience of being around those who knew science but was unable to get to know ISI for himself and his students. There was no evidence of impact as a result of the ISEP intervention for Jack.

To answer our research questions, Jack had many opportunities to develop ISI through the summer research experiences and in class professional development support. However his fragmented understanding of ISI did not translate into his classroom practices. Also, as a result of not attending the professional development workshops had little opportunity to connect his summer experiences into an application of instructional strategies that reflected ISI. Jack's knowledge and beliefs of his students also was critical in identifying the barriers to successful implementation of ISI. Jack demonstrated some development during the summer research experiences and his own prior knowledge. His PCK knowledge development was limited by his experiences as well as his beliefs on what was necessary for ISI to work within his classroom.

Jack falls within the novice category of an instructor as he demonstrated minimal and fragmented understanding and practice of ISI. Jack's content knowledge increased as evidenced by his exposure and understanding of Earthquakes in the science laboratory he worked in, however his pedagogical skills were limited by his inability to work without a bigger understanding of the process of ISI and his beliefs about the conditions necessary to implement ISI within his classroom practices. This representation below demonstrates Jack's categorization as a novice as demonstrated by his understanding and implementation of ISI practices.



Case Study #2: Chris

Conceptions and Development of Interdisciplinary Science Inquiry Knowledge

Proposal:

In Chris's proposal, the plan was to develop a classroom model of a sustainable system. "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's conceptions of Inquiry were stated as:

> "Inquiry is the process by which students learn by doing. When a student's interest is piqued to motivate them to find an answer they will search for answers and in the process develop meaningful knowledge."

Chris also identified challenges to conducting interdisciplinary science inquiry in middle and secondary school science such as, developing interdisciplinary unit that are integrated, getting teachers on board to implement new methods of teaching and finding time within the various subjects' curriculum to implement the plan.

Summer Research Context Observations:

Chris involved himself in University laboratories where they did the water quality analysis as a group and he also spent time inquiring and learning about sustainability and put together a system for use in the classroom. Chris was exposed to university research laboratories and scientists shared their experiences on the work they conducted. Chris also worked independently on researching materials and taking time to put his system of Aquaponics together.

Each teacher's goal during the summer was to connect the research experience to their classrooms. They sought out a mental map of how and where this would fit within the pacing guides and curriculum maps they followed. There were no explicit messages that informed teachers they were experiencing ISI during their summer research experience. As a result much was left to the interpretations of teachers to translate their own conceptions into their classroom practices.

Summer Log Sheets:

Chris did not turn in any summer log sheets and lost an important opportunity to be reflective on the process of ISI and how he could translate his experience into this classroom practices.

Summer Poster Session:

Chris's poster focused on his summer experiences and included the following as goals for his students. "(a) Determine feasibility of a classroom Aquaponics system, (b) develop a modular aquaponics system for us in the classroom, (c) use recycled material for constructing the system (d) Determine acceptable material for constructing the system (e) Form an Aquaponics club to maintain classroom model (f) Use ion selective probe ware to asses water quality (g) To engage students with science based activities and (h) To make learning science fun!!" Chris demonstrates his understanding of the elements of ISI and its potential application in his classroom more so than the other teachers. Most of his goals are for him to accomplish and has few indicators of how students are going to involve themselves in inquiry.

Ongoing Professional Development Workshop Evaluations:

Chris attended two Professional Development workshops during the year of the grant. He professed to attend these workshops because of the convenience of it being held at his school. 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 grant.

Although it was good that Chris attended some PD he did not gain an opportunity to reflect on how he would translate his learning of ISI into this classroom practices. This was a key piece in having teachers form a seam between what they learned and what they intended to do.

Teacher Interview:

During the interview with Chris, he explained to me 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'd do have scalable model and I have it in my classroom and I am very satisfied, and of course you take that the students, and then of course it is to have students getting involved and we are getting students involved, so that will be the ongoing."

Chris had ideas as to how he would consider implementing his summer experience and shared them with me.

"Our upper-level students participating in a writing contest with the Sierra Club and it is on sustainability and those kinds of things and so I am thinking that some of those students that are in the club this is not that won't come to fruition and of February but I'm pretty sure that some of them will be writing papers using that model and others will do broader….. But I think some of the club members that are in the upper level will be using that so…. So we are just pulling it in we are pulling it in that way."

Chris also demonstrated that he was utilizing his summer experience model with students within his teaching. While he made connections to his model it was still at a low level of inquiry and ISI. He made minor connections but was still missing the big picture as to how this translated into practices for students.

> "Well having the model in your classroom allows the kids to actually visualize the growing process, and nutrient cycling. We are talking right now we are in our environmental lab we are testing water samples from a lake and we are testing nitrates. And nitrates are one of the one of the variables in our Aquaponic systems so we can take the nitrate test, we are testing these water samples and walk right over and t test the tank… And the kids go we have a lot of nitrates in the tank!!! And so they know that, and then we can expand that to so what does that mean? What do we have to do? Is it too much? Where is the balance? And we are pushing into those areas now to so…"

Chris also mentioned the challenges he would face when trying to implement his summer research. He expressed concern over the state of student abilities. This is a key piece in teacher implementation of ISI. Having strong ideas and beliefs about what students can accomplish seriously hinder student experiences of ISI.

> "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."

He cited an example that when asking students where lettuce comes from, they referred supermarket. So, rather than understanding that most students today within the United States are far removed from farming and agriculture, he targeted that as a lack of understanding on the part of urban students. He listed the requisites for student learning of ISI. This belief system limited the experience of ISI by his students. Chris also believed that students needed an understanding of the basics before inquiry could be implemented. For example, he stated,

> "So, we have to first establish that level of knowledge before we can embark on the journey of inquiry and if we do it any other way I coined this term about six years ago and that is, ignorance adrift on the sea of inquiry…. 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 it's like the discussion is going nowhere and is getting ridiculous and when we back it up we realize that will wait a minute our students wanted to know what sewage is."

Chris also stated that the felt his role as a teacher was to teach from bottom up even though he realized the importance of Inquiry. This view indicates that Chris lacks in his knowledge of the importance of pedagogical practices that are linked to student learning. He felt that conceptual understanding only could be accomplished in it was preceded by the basics, facts and vocabulary. These notions tie into his beliefs about how students within his urban setting could learn. He made explicit the conditions and criteria needed for ISI to occur.

> " So I do view my job to be very basic instruction, but you can't just do that in science and abandon the inquiry part because science is inquiry so, so then we have to then we take them on that journey, try to expand that and the curriculum that we use is very inquiry-based. But in order to do the project we have to teach the basics, so, we have our project already set up the wall we do is we will spend, we will spend a week, a couple class sessions doing basic vocab, what is sewage and breaking it down so that before we step into it they have some knowledge."

Chris's understanding of ISI was knowledgeable. Using his example of the aquaponics system Chris stated,

> "Interdisciplinary science inquiry I believe is the pulling in of other disciplines in this case Biology, Environmental science so the area of building of putting together but system, the movement of the water the physics involved is all part of this. We have siphons running which have to do with pressure and gravity and the differences between them."

> When I asked Chris about what strategies he would utilize to teach ISI he stated,

> "There is definitely the observation and inquiry strategy works when you have something for them to observe and test you are not dealing in the theoretical and you're dealing with the abstract and you're dealing in the concrete."

He went to say further that,

> "Certainly inquiry would be right up on it and there's some expository explicit, you know the pump is putting the water through here and here and these joints are held together by this and that you know because again you are exposing them to things that are brand-new you have to tell them exactly what's happening… because that is going to look at it and say oh that's a 90° elbow attached in a you know or that is a and screws and to the pipe and you've got tell them you've got to use the technical terms and I try to use the technical terms that would apply in this case plumbing within the plumbing trade so that they if they were talking to somebody about it's be it a plumber or engineer or homeowner that has the idea of plumbing it is a standardized to the industry. That would be expository and explicit. It is the same way I teach science it is and it is explicit linked with inquiry."

Despite Chris's demonstration of a sound understanding of ISI and ideas about implementation, his classroom lesson only demonstrated an intermediate level of implementation. His ideas on how science works was not aligned to his instructional practices. There was little evidence of ISI in his classroom. The observations made describe what was presented by Chris.

Implementing Interdisciplinary Science Inquiry Strategies demonstrated by Instructional Strategies

Classroom 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 reviewed the concepts of photosynthesis and respiration and spent time with knowledge and recall of the meaning of symbols and the formulas. He utilized a KWL chart and had student fill it out as a whole group. 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." Chris believed that students needed a certain set of skills prior to conducting inquiry and that the focus on his grade 9 academy was on teaching students' behavior and rules so that they could use that as a springboard for learning. The application of his summer research is clearly reflected in his knowledge about students and their learning.

Student Interviews:

I also interviewed Chris's students who were asked the same set of questions as Jack's related to their interest in learning science topics of their choice and having to do with local issues that affected them. Some of the responses Chris's students shared with me were,

> "I would like to study about human anatomy and dissections." Another student said, "I don't like science but when I was a kid I used to like to learn about plants and animals. I would like to learn more about them today but I like to learn about nursing." Another student talked about studying lake pollution and that in Mr. Chris's class they had done some water sampling of a lake."

We also discussed how to conduct research and go about problem solving using tools and help of scientists in the area of research. Students were eager to talk about learning now that the topics piqued their interest.

Debriefing of Student Interviews with teachers:

When I shared what the students were interested in learning and if it was a possibility in Chris's class, he responded with a pleasant smile and said,

> "These are all the topics that I have introduced to them in my classroom". He mentioned that the lake water he brought in was fictitious. I probed further to see if he would consider doing this type of research in his classroom and spend the time required to do it using a real lake nearby?
>
> I also asked if he would consider introducing dissections to the students. His response was that,
>
> "In the past I didn't do it because I didn't feel my students could handle it and that being interested in scalpels and being trusted with scalpels were two different things. I think I have one class that could be trusted but not the others." I inquired if he was concerned with students getting into accidents and he said that was not his main concern, rather "I don't want to take on the management." I encouraged him by saying that when students are involved and are interested they manage themselves. In response Chris said, "I have different experiences than you and I am more concerned about the other people in the room who are not into the lesson and may cause trouble for those doing it."

As I continued to probe Chris with further questions on his consideration to teach about lake pollution in the field, he said since there is interest from his students he would consider it but, "I would keep it large for them, something like an excursion you know for cleaning up, pulling tires out of the river, I think I could handle." Again Chris's inhibition to conducting inquiry with his students demonstrates his beliefs about the inability of his students to do science as well as the inconvenience that such change may require of him.

Although in his original poster session Chris had talked about using probes and learning them at the university summer research, he was not open to using them in the classroom because, "Primarily it might be my fault because I would be the one and this is but I am not willing to make that investment time and money, I just am not buying into it." Chris did consider leaving some curriculum out in order to compensate student interests.

Later in his interview I asked him if teachers' should consider the students interests in teaching. He felt that teachers motivate students by their own interests and passions and that every teacher should develop passions so students could be motivated, not that students should motivate teachers to be excited about their ideas. Chris's ideas about student learning leaned toward them being receptacles of information and that motivation and drive came from teachers not student interests. His lesson reflected his views on what students can and cannot do. He did admit to considering changing his curriculum because deeply he felt that the curriculum, although important,

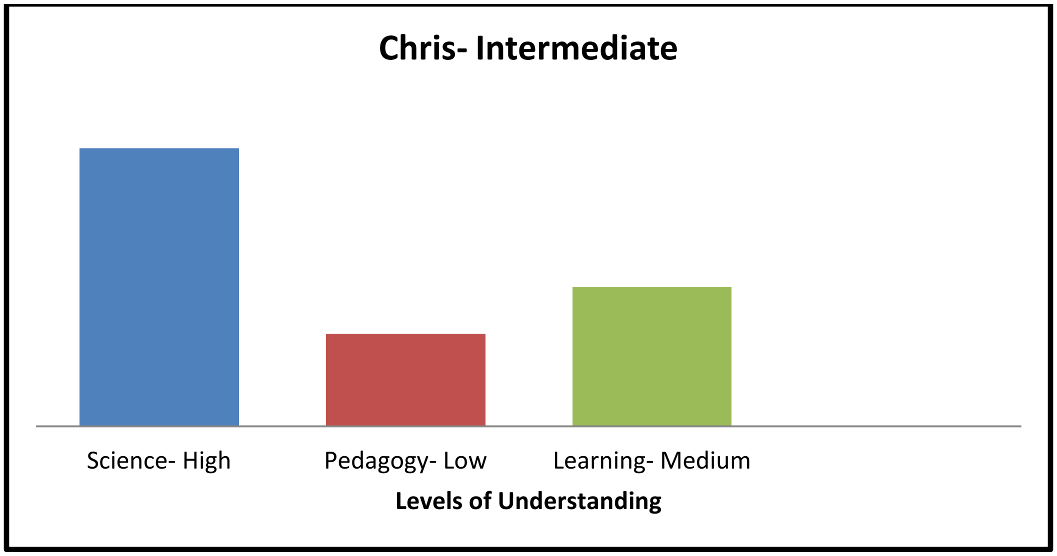
> "The curriculum does not run my life and even though that doesn't really fit anywhere with what we're doing other than a supplemental and doesn't fit the pacing guide and it puts us a day behind if there is such a thing then then we then the motivation aspect which again out of that's certainly outweighs the curriculum."

Summary of Chris's findings:

Chris had a good background in science content prior to the summer research experience and he developed his content knowledge further as a result of it. He utilized his summer experiences and demonstrated his understanding of ISI as exemplified by the sustainability model he created and his ideas about the way in which it could be implemented in his teaching practices. 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 knowledge of science and community was sufficient however his knowledge of his students and beliefs about what they could accomplish, limited his application of ISI. He was teacher centered and focused rather than on his students learning and was limited by what he believed his students could do.

Chris also attended one professional workshop in which he stated that he had a clearer understanding of ISI. Had he stayed on and participated he may have been able to learn about instructional strategies, the area in which he lacked.

Chris had a sound base of content knowledge which was further developed through his summer research experiences. Since he attended only one professional development session he did not have the opportunity to gain an understanding of instructional strategies he could have utilized reflecting his summer research. During the summer he did not fill in the reflective log sheets which may have helped him develop his implementation ideas. He developed his PCK however was unable to translate his experience and understanding through instructional strategies in his classroom. His implementation of ISI was also limited by his beliefs about what prerequisites his students needed to conduct inquiry. He was categorized as intermediate as a result of his application of the research experience. This representation below demonstrates Chris's categorization as intermediate as demonstrated by his understanding and implementation of ISI practices.



Case Study #3: Stash

Conceptions and Development of Interdisciplinary Science Inquiry Knowledge

Proposal:

Stash's goal for his summer research was to work at a local cancer institute so that he could better understand the role of the immune system in cancer. He intended to align this experience into the body systems unit that he taught in his biology course. Stash's conceptions of ISI were stated in his proposal.

> "This is a method of teaching in which a science concept is taught across several other disciplines such as mathematics, English language arts, social studies and technology," which reflects his understanding of it within the context of the integration of the NYS adopted Common Core curriculum in his district. He stated that although the learning of the science concept and lab skills will primarily occur in the science classroom, other classrooms will be a component of the overall project. For example, the writing of the project could be developed in the ELA classroom while a component that includes probability, graphing, and data analysis could be conducted in the math classroom. Studies have shown that interdisciplinary units can have positive effects on student enthusiasm, attendance rates, and standardized test scores."

Stash seems to articulate his understanding of ISI as he connects his work in the summer to cross curricular subjects and expressed how he can incorporate them in student lessons. Stash also recognizes the challenges that may come about as he tried to implement ISI. Some examples are the need for more time to incorporate ISI into other subject areas, and getting other teachers on board to implement the plan. Despite the challenges he may face, Stash had a clear goal in mind for his implementation plan. His focuses on connecting his summer research to his current teaching practices through lessons involving the Immune System. He had stated this in his research proposal and we can see that he is driven to carry out his goals.

> "The current Living Environment curriculum designates 1-2 weeks in April for the study of the immune system. At this time of year, the entire school is strongly focused on the upcoming state ELA and math exams and science becomes somewhat of an afterthought. This presents an opportunity for an interdisciplinary science unit that incorporates ELA and math skills. Students will be engaged in using ELA and math on a higher level that has real world relevancy. The possible benefits of greater student enthusiasm and higher attendance rates at this time of the school year could positively influence student performance on the upcoming state tests."

Summer Research Context Observations:

Stash proposal 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 research laboratories were technology rich and the professionals working explained the most detailed procedures with the goal to link the learning to the classroom environment.

Each teacher's goal during the summer was to connect the research experience to their classrooms. They sought out a mental map of how and where this would fit within the pacing guides and curriculum maps they followed. There were no explicit messages that informed teachers they were experiencing ISI during their summer research experience. As a result much was left to the interpretations of teachers to translate their own conceptions into their classroom practices.

Summer Log Sheets:

Stash did not turn in any summer log sheets reflecting how he was internalizing the research process and reflecting on its connections to ISI. This would have been a beneficial process for Stash to engage in and would have aided him in thinking about his practices in advance, well before implementation.

Summer Poster Session:

Stash's poster summarized his summer research experiences in the various laboratory settings. Because Stash had limited ability to interact with the technology and testing at the Cancer institute he spent a great deal of time learning about and discussing the ways in which he could translate his work into this classroom. He identified his goals for implementation as described in his proposal. Because Stash had indicated he needed help with the implantation process, it was not clear from his poster how and what he planned to do in his classroom.

Ongoing Professional Development Workshop Evaluations:

Stash attended the professional development workshops regularly. He participated and actively engaged himself in the activities. This exposure increased his understanding of ISI and its potential implications within his classrooms. He developed knowledge of instructional strategies as well.

Teacher Interview:
During Stash's interview I asked him what he liked about teaching and how it aligned with grant 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 is a big place in my room."

When I inquired about how he planned to implement his summer research experience into his classroom practices and the challenges he may face and, he stated that,

> "well for the cancer institute, it is actually kind of fitting early on and this is why I was hoping to do more activities because we're on cells and so the next time that it's really going to come around would be when we do human body systems so that will be there is going to be in the spring so is going to give me some time to diffuse some of these ideas into some of these lessons. I mean it ties right in and it's you know I teach living environment and life science and the cancer institute and you know I mean that it, the backbone of what goes on there with life science and also to sum things up we have never gotten into but a lot of the technology will fit right into my physical science classes as well. For example the flow cytometry uses lasers and they use wavelengths you know… The excitement of electrons and all that that will tie into so I mean there is it's not like how can I fit it in, it's how much time will I have a plan to fit it in. That is really what it is. I mean it is really finding the time to plan."

I also questioned Stash about his purpose for teaching science and he responded that,

> "the point of science is to actually make our lives better, and in some way safer for develop technologies that moves us further along in some way. And in the cancer institute you see this firsthand you see how all of these different disciplines are all being put together to solve a problem, to diagnose, cure patients something that is real and relevant and tangible and it stresses the importance you know besides all of this testing you know that we are so focused on so, that is one thing where on a daily basis I'm like yeah I need my kids to pass these tests but at the same time I need to make sure that they are getting the big picture as well the big understanding you know that science and school is more than just passing a test and there is a you know deeper relevancy, you know."

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 way 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 ISEP partnership.

Implementing Interdisciplinary Science Inquiry Strategies demonstrated by Instructional Strategies

Classroom Observations:

During the lesson observation 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. There were graduate and undergraduate students as well as university staff in the room to assist with the lesson. 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. Students were engaged and also enjoyed themselves. Stash's lesson invoked some explanations and instruction giving during the lesson. The lesson was situated well within a larger context of learning in the curriculum as well as connected to student's lives. There was some redirection required and 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. Students practiced Inquiry process skills such as questioning, problem solving, analyzing data and discussing data with peers. 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 professional development workshops.

There were graduate and undergraduate students as well as university staff in the room to assist with the lesson. The PhD. Student was instrumental and a vital part of the planning and implementation of technology in the lesson. His 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 the implementation. With so many knowledgeable students in the room who had an opportunity to develop rapport and relationships with students made the lesson go particularly well. Student's interest in the topic and the relevance to their lives made it all the more interesting. "I have a lot of help this year with PhD students and the master's student and the graduate students so I am doing things a little differently."

Student Interviews:

I had the opportunity to speak with Stash's students in his classroom as I had spent time during the planning and set up phases prior to his lesson observation. His students had an ease and comfort in his classroom and were open and expressive in voicing their desires and interests in science. They expressed interest in learning through projects and studying concepts that interested them along with what was required for the curriculum. For example a student stated, "I like to learn about the human body and all the things that can happen to it, I want to be a doctor one day." Another student commented on how Stash had taken them to the museum and there he had found an interest in learning about sports and that he did not know how much science it had. I saw it in one of the exhibits in the museum." Another student said," I like to work with computers and learn by looking at things and how they work in science."

Their comments were well received by Stash who had a deep understanding of their culture and needs of his students. He approach towards his students was one of consideration into fulfilling their needs as well as keeping in the forefront of his goals to have his students pass the state assessments. He recognized that his students had challenges and came with varying needs and that would not be a barrier for him to conduct real science as well as keeping in mind that passing school assessments and graduating was equally important.

Debriefing of Student Interviews with teachers:

I shared with Stash that his students shared that they enjoyed learning with a hands on approach and I asked if he would teach in that fashion in his classroom. He responded that, "what I found is that kids actually I can give them a project, they can do a project and learn the concepts, I find that they actually retain stuff for tests better."

He also felt inquiry was important.

> "I already infused a lot of inquiry and interdisciplinary stuff in my classroom and I actually said when I was speaking you know light let the kids see it in action." He also shared that he planned his lessons around his student's interests. "Well anytime that you are doing something that you think is going to engage the kids you're usually right and I knew that this lesson was going to engage the kids and when we began to started to talk about the cancer institute and what it did, I didn't have to tell the kids to stop talking they just listened. So they're interested in it because it is something that is right here in the community right down the street."

Stash also recognized the nature of ISI when conducting his lessons. His lesson had the major defining characteristic of ISI. When asked how ISI connected to the lesson he demonstrated for us, he responded that,

> "the whole interdisciplinary idea is where it ties everything together they're using computers they are using an app that they've never seen it opens up a whole new way of looking at pictures or data in a way and then analyzing it's you know in a public way seeing a bigger picture that relates to their lives that's the benefit that is the benefit, the benefit is in the lesson itself even though it's not like bringing this lesson in like creating some you know you know something grandiose it's the lesson itself that is the celebration."

Stash also clearly recognized the bigger picture of science. For Stash, science was not teacher centered, and a way to transfer knowledge and facts to students. It exemplified a larger understanding of the big picture and the practices that would help students gain that type of knowledge.

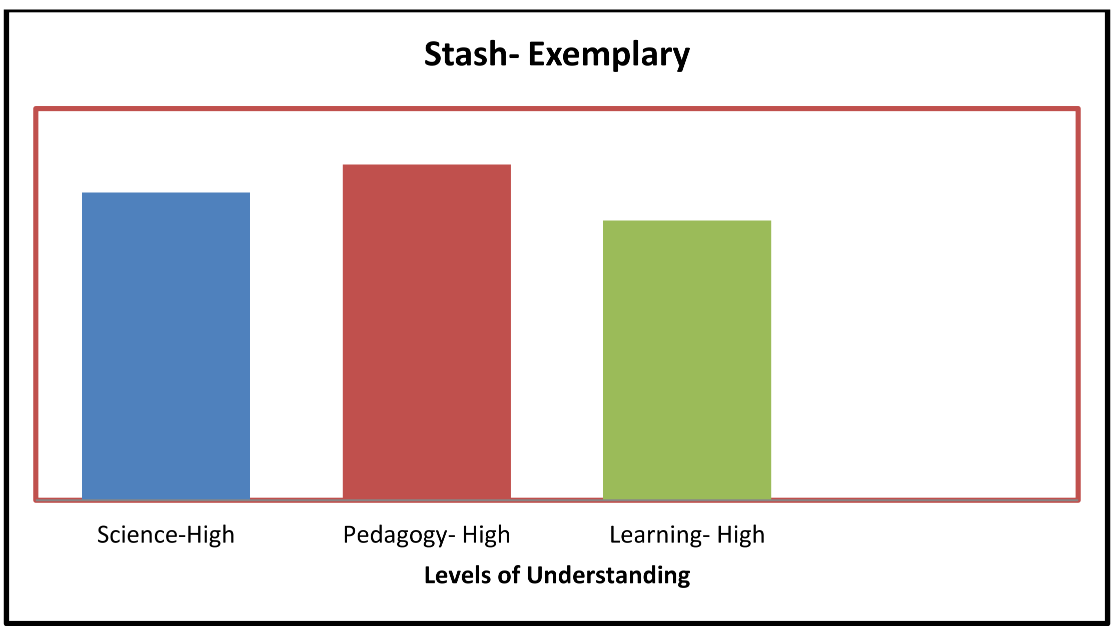
> "It is more important that they have a broader understanding of science and how it relates to the public, the health issues and all that. He shared that at the cancer institute he say all of the higher-level thinking and the problem-solving and all of that that goes on there you know it kind of opened my eyes.. I had been focusing on testing and now it helps me to see it in balance. I am also going to strive to tie in all this ISI and project-based

learning but at the same time at least that tangible thing that gets what this kid is ahead of the game going to high school at least in terms of the exams and graduating."

Summary of Stash's findings:

Stash had clearly demonstrated an interest in wanting to connect his summer research experience at the cancer institute to his classroom practices. Stash had many resources available to him such as his experience from the summer, volunteers in his classroom, his interest in his students, having access to equipment as well as an understanding of methods and strategies. Stash with the help of these resources available to him, worked with his post doctorate student, his cancer institute resources and the learning he acquired through his professional development experiences to create a teaching and learning experience for his students. Stash, of all the participants in this study utilized his own personal and developed strengths in science content, his deep understanding of his students and context and applied it to a lesson that was exemplary of ISI characteristics.

Stash developed both his content as well as knowledge of instructional strategies which contributed to the development of his PCK. He, in the continuum of the three teachers demonstrated the most complete understanding and application of ISI.



Conclusion and Discussion

Reflecting on our findings we conclude that teachers interacted with the grant 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. Teachers had the opportunity to develop science content knowledge as well as knowledge of instructional strategies to assist them in the development of their PCK. As a result of data analysis and findings some major themes emerged.

Theme 1: Teachers perceptions and conceptions of interdisciplinary science inquiry evolved 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 professional development 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. In Jack's case he felt ISI was hands on work and across disciplines. Chris believed inquiry was learning by doing and Stash shared that it was a method of teaching that involved cross curricular connections. Stash's understandings of these cross curricular methods were informed by the application of the common core curriculum within his school district. These initial conceptions of ISI evolved as the teachers engrossed themselves in various research experiences at the university and research settings.

Theme 2: The summer university research experience and professional development 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. Jack wanted to explore the conceptualization of Earthquake development and prediction and bring that knowledge back to his classroom. Jack hoped for a direct translation of what he saw and did in the Earthquake lab to his classroom practices. Jack's desire to translate content based activities directly demonstrated a lack of deep understanding of ISI.

Chris demonstrated interest in creating a sustainable aquaponics model to springboard inquiry learning. Chris had great ideas about connections his students could make utilizing his aquaponics model and he demonstrated a good progression in the understanding of ISI through his explanations and goals for his classroom implementation.

Stash desired to work in a cancer institute and link his learning to the biology curriculum he taught. He specifically wanted to connect the immune system and the role it played in cancer. He clearly articulated his interest in cancer research and its applications to his curriculum. Stash had a good understanding of ISI within his learning context; however, he initially had difficulty seeing how this would unfold.

The professional development offered was taken advantage by Stash who attended all workshops focusing on implementation of ISI through a variety of instructional strategies. Chris attended two of the workshops while Jack attended none. This experience of having an opportunity to develop strategies was clearly evident when classroom observations were conducted.

There were visible connections to teachers' initial conceptions of ISI as stated in their proposals and the way in which those conceptions were carried into their research experiences. The teachers who came in with a more comprehensive understanding of science inquiry continued to develop along the path of increasing their knowledge further through the summer research experience and were also the ones most interested in continuing to develop their knowledge through professional development workshops. These workshops allowed teachers to channel and hone this knowledge into practical learning experiences for their students.

Themes 3: The varied interpretations of ISI impacted the way in which teacher's 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 demonstrated his understanding of ISI by conducting a review of science questions as his lesson. He projected questions on a board and after brief discussions students shared answers. The questions were directly from past state assessments. It was a teacher centered lesson with no notable characteristics of ISI instructional strategies. 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, professional development and the views and beliefs he held about his students' abilities.

Chris demonstrated his understanding of ISI through his lesson on the concept of photosynthesis and respiration. The lesson was teacher centered and the role of students was to review science concepts, watch a video on material cycles, followed by a brief discussion on how the lesson connected to his sustainability model. 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 professional development 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. His emphasis on inquiry practices, high level of science content and a connection to students' lives made his lesson exemplary.

It is important to note that the variation in pedagogical practices resulted from teacher experiences and beliefs about science, pedagogy and learning. Their PCK development was affected by these factors. Teachers identified both success and barriers for implementation. Some of the barriers that teachers faced to fully integrating ISI were in their lack of understanding of ISI as a practice. They focused more on direct translations of their summer experiences into their classrooms and pacing guides and a need for the same equipment, rather than focusing on the process of ISI they experienced over the summer. They failed to see that the process of ISI could be applied to any of the content they taught. Teachers in this study made explicit their beliefs about what science means to them and what its practice should entail. Although they could verbalize and cognitively articulate their views on ISI, the practice was much more challenging. Teachers made explicit in this study what they would teach to students and in what fashion. Student generated data challenged notions of whether teachers would teach ISI. Their belief about what their students could accomplish was a major factor in the implementation of ISI.

Because urban environments have their own set of challenges these need to be taken into account for successful grant implementation. To address the barriers that teachers identified, we need to continue professional development which addresses the need to bridge the gap between knowledge of ISI and effective implementation of ISI. In addition, teachers must also be able to examine their beliefs about science, pedagogy and learning continually and reflect upon how it played a role in their implementation of ISI. Well -constructed professional development can cause shifts in beliefs in both experienced and seasoned educators.

Implications for Educators

In order to increase an understanding and application of interdisciplinary science inquiry, teacher professional development must continually contribute to teachers' growth in knowledge of both science content and pedagogy.

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 professional development 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. One of the limitations of this study was in the area of full participation. If teacher development is to take place all teachers must engage in the learning experiences provided to them. For example filling out log sheets would have been a reflective process for teachers. It would have helped them bridge the connection from their research to practice in the classroom. Attending all professional development sessions would 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 affects the variability in teaching and learning outcomes of students.

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 in science content and ISI processes, teachers PCK may not have developed. (vanDriel et. al. 2011) conclude that unless teachers have acquired a "deeply principled conceptual change in content knowledge, the development of PCK is unlikely to occur."

Teacher feedback is also an important resource so interventions can be tailored to meet the needs of teachers resulting in successful ISI implementation. This research is worthwhile to help us answer the questions such as what measure are necessary to help teachers develop ISI knowledge and successfully implement those understanding within their contexts.

References

Anderson, R. D., & Helms, J. V. (2001). The ideal of standards and the reality of school: Needed research. *Journal of Research in Science Teaching, 38*(1), 3-16.

Anyon, J. (2001). Inner cities, affluent suburbs, and unequal educational opportunity. In J. Banks & C. Banks (Eds.), *Multicultural education: Issues and perspectives* (4th ed., pp. 85-102). New York: John Wiley.

Bell, B., & Gilbert, J. (1996). *Teacher development: A model from science education*. London: Routledge Falmer

Benchmarks for Science Literacy (AAAS 1993, 2008)

Blumenfeld., P, Soloway., E, Marx., J, Krajcik., M & Palinscsar., A. (1991). Motivating Project Based-Learning:Sustaining the Doing, Supporting the Learning. *Educational Psychologist. 26(3-4),*369-398.

Cotton, D. R. E. (2006). Implementing curriculum guidance on environmental education: The importance of teachers' beliefs. *Journal of Curriculum Studies, 38*, 67–83.

Crawford, B. A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching, 37,* 916–937.

Dresner, M. & Worley, E. (2006). Teacher Research Experiences, Partnerships with Scientists, and Teacher Networks Sustaining Factors From Professional Development. *Journal of Science Teacher Education, 17,* 1-14

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (2007, eds.). *Taking science to school: Learning and teaching science in grades K-8.* Report of the Committee on Science Learning, Kindergarten through Eighth Grade. Washington, DC: National Academy Press.

Duffee., L & Aikenhead., G.(1992). Curriculum change, student evaluation, and teacher practical knowledge. *Science Teacher Education, 76(5),* 493-506.

Ely, M., Anzul M., Friedman, T., Garner, D., Steinmetz, A., (2006). *Doing Qualitative Research Circle Within Circles.* London and New York; RouteledgeFalmer, Taylor and Francis Group (Fraser-Abder, Atwater, &Lee, 2006)

Friedrichsen, P., Abell, S., Pareja, E., Brown, P., Lankford, D., & Volman, M. (2009). Does Teaching Experience Matter? Examining Biology Teachers' Prior Knowledge for Teaching in an Alternative Certification Program. *Journal of Research in Science Teaching, 46(4),* 357-383.

Glesne, C (2006*). Becoming Qualitative Researchers An Introduction*. Pearson Education, Inc. (Haney, Czerniak, & Lumpe, 1996).

Hannaway & Kimball, 2001; Kahle, Meece, & Scantlebury, 2000; Lynch, 2000; Tobin, Roth, & Zimmerman, 2001.

Johnson, C. C. (2006) Effective professional development and change in practice: Barriers teachers encounter and implications for reform. *School Science and Mathematics, 106*(3), 1-12.

Krajcik., J, Blumenfeld., R, Marx., R, Bass., J & Soloway., E. (1998). Inquiry in Project-Based Science Classrooms: Initial Attempts by Middle School Students. *Journal of the Learning Sciences, 7(3-4)*,313-350.

Katehi.,L, Pearson., G, & Feder., M. (2009). Engineering in K-12 Education: Understanding the Status and Improving the Prospects. National Academy Press at http://www.nap.edu/catalog/12635.html

Loucks-Horsley, S., & Matsumoto, C. (1999). Research on professional development for teachers of mathematics and science: The state of the scene. *School Science and Mathematics, 99*, 258-271

Little, J.W. (1993). Teachers' professional development in a climate of educational reform. *Educational Evaluation and Policy Analysis, 15*, 129–151.

Loucks-Horsley, Hewson, Love & Stiles, 1998; National Commission on Teaching and America's Future, 1996.

Luft, J. A. (2001). Changing inquiry practices and beliefs: The impact of an inquiry-based Professional development programme on beginning and experienced secondary science teachers. *International Journal of Science Education, 23*, 517–534.

Magnusson,S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. Lederman (Eds.), Pedagogical content knowledge and science education (pp. 95–132). Dordrecht, The Netherlands: Kluwer Academic Publications.

Munby, H., Cunningham, M., & Lock, C. (2000). School science culture: A case study of barriers to developing professional knowledge. *Science Education, 84,*193-211.

National Research Council. (1999). *How people learn: Brain, mind, experience, and school.* Committee on Developments in the Science of Learning. J.D. Bransford A.L. Brown, and R.R. Cocking (Eds.) Washington, DC: National Academy press.

National Research Council. (2011). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Washington, DC: National Academy Press.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press.

Nargund, V. & Liu, X (2013). Understanding Meanings of Interdisciplinary Science Inquiry in an Era of Next Generation Science Standards. Paper presented at the MSP Learning Network Conference, Washington, DC.

Nargund-Joshi, V., Liu, X., Chowdhary, B., Grant, B., Smith, E. (2013, April). Understanding Meanings of Interdisciplinary Science Inquiry in an Era of Next Generation Science Standards. Paper presented at the annual meeting of National Association for Research in Science Teaching, Rio Grande, Puerto Rico.

NGSS Public Release II. (2013, January 1). Retrieved from http://www.nextgenscience.org/next-generation-science-standards

National Science Education Standards (NRC 1990, 1996, 2001)

Odom, L. (2001). Inquiry-based field studies. Science Educator: *The National Science Education Leadership Association Journal, 10*(1), 29–37

Park., S. & Oliver., S. (2008). Revisiting the Conceptualization of Pedagogical Content Knowledge (PCK): PCK as a Conceptual Tool to Understand Teachers as Professionals. *Research in Science Education, 38(3),*261-284

Roehrig & Luft, 2004a & b;Wallace & Kang, 2004; Windschitl, 2004.Ruby, A. (2006). Improving science achievement at high-poverty urban middle schools. *Science Education, 90,* 1005-1027.Seidman, I. (2006). *Interviewing as Qualitative Research.* New York: Teachers College Press

Seung, E., Bryan, L., & Haugan.,M. (2012). Examining Physics Graduate Teaching Assistants' Pedagogical Content Knowledge for Teaching a New Physics Curriculum. *Journal of Science Teacher Education, 23,* 451-479.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher,15*(2), 4-14

Shulman, L. (1987b). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57,* 1-22.

Singer, J., & Lotter. C., & Feller, R., & Gates, H. (2011). Exploring a Model of Situated Professional Development: Impact on Classroom Practice. *Journal of Science Teacher Education, 22*, 203-227.

Supovitz, J.A., & Turner, H.M. (2000). The effects of professional development on science teaching practices and classroom culture. *Journal of Research in Science Teaching, 37,* 963-980.

vanDriel, J., Beijaard, D., & Verloop, N. (2001). Professional Development and Reform in Science Education: The Role of Teachers' Practical Knowledge. *Journal of Research in Science Teaching. 38(2),* 137-158.

Waslander, S. (2007). Learning about innovation. Review of scientific research on sustained innovation in secondary education.

Wislon.,M. & Berne.,J. (1999). Teacher Learning and the Acquisition of Professional Knowledge: An Examination of Research on Contemporary Professional Development. *Review of Research in Education. 24,* 173-209.

Yerrick, R. Parke, H., & Nugent, J. (1997). Struggling to promote deeply rooted change: The "filtering effect" of teachers' beliefs on understanding transformational views of teaching science. *Science Education, 81*(2), 137-159.

Yin, R. (1994). *Case Study Research Design and Methods.* Thousand Oaks California: Sage Publications.

Zohar, A., & Dori, Y.J. (2003). Higher order thinking skills and low achieving students- are they mutually exclusive? *Journal of the learning Sciences, 12,* 145-182.

Zech LK, Gause-Vega CL, Bray MH, Secules T, Goldman SR (2000) Content based collaborative inquiry: a professional development model for sustaining educational reform. *Educational Psychology 35(3):20*