Rommel J. Miranda and Julie B. Damico

Changes in Teachers' Beliefs and Classroom Practices Concerning Inquiry-Based Instruction Following a Year-Long RET-PLC Program

Abstract

This mixed-methods study examines how engaging science teachers in a summer Research Experiences for Teachers (RET) followed by an academic-year Professional Learning Community (PLC) focused on translating teacher research experiences to inquiry-based classroom lessons might facilitate changes in their beliefs and classroom practices regarding inquiry-based instruction. Supported with NASA funding, fourteen high school science teachers participated in a large mid-Atlantic university's year-long RET-PLC professional development program. The findings of this empirically-based study suggest that a summer RET program augmented by an academic-year PLC component can help teachers to shift their beliefs from a teacher-centered to a more student-centered approach. However, changes in classroom practices which demonstrate that teachers had transitioned from the use of teacher-centered to reform-centered practices were limited. Moreover, the study's findings have several implications for developers of professional development programs for in-service science teachers and science education researchers.

Introduction

Science education reform efforts strongly emphasize the use of an inquiry-based approach in K-12 science instruction (Singer et al., 2005). There is no shortage of research affirming that teachers who implement inquiry-based instruction in their classrooms can enhance students' science process skills, habits of mind, problem-solving skills, and understanding of the nature of science (Hofstein & Lunetta, 2004). Research studies further suggest that the successful implementation of inquiry-based instruction requires not just an understanding of the process of science, but a more sophisticated, well-developed knowledge of science inquiry (Akerson et al., 2000; Crawford, 2007; Roehrig & Luft, 2004), teaching and learning of science (Blanchard et al., 2009), and science content and pedagogy (Gess-Newsome, 1999; National Research Council, 1996).

While research recommendations advocate that teachers should be spending more time using an inquiry-based approach that incorporates problem-solving contexts and less time in didactic presentation of facts (Southerland et al., 2003), studies suggest that teachers have very little experience with inquiry in a formal scientific sense and possess very naïve and informal conceptions of inquiry-based instruction (Anderson, 2007; Blanchard et al., 2009; Windschitl, 2004). This apparent disconnect between how science is done by practicing scientists and how it is taught in schools may stem from teachers' lack of experience with authentic science research (Lotter et al., 2007).

To address this issue, a promising form of professional development, Research Experiences for Teachers (RET), has emerged over the past two decades and is premised on the notion that experience in the practice of science improves the quality and authenticity of science teaching and thereby increases student interest and achievement in science (Silverstein et al., 2009). Research experiences generally refer to the contexts in which teachers are mentored by research scientists and conduct scientific investigations (Kardash, 2000). Thus, what participating teachers believe they can do with new ideas that are generated from their research experience and how much they value the new element may indicate the extent to which changes are made in their classroom practices (Pop et al., 2010). A couple of recent studies have documented RET participants' translation of research to the classroom (Klein-Gardner et al, 2012; Klein, 2009). However, while RET programs allow teachers to experience scientific inquiry in the hopes that these experiences will then translate to inquiry-based lessons in the classroom, limited empirical evidence exists to document the effectiveness of RET programs in accomplishing this goal (Blanchard et al., 2009).

Another practice in the area of teacher professional development, Professional Learning Communities (PLC), has the potential to help teachers understand scientific inquiry (Demir & Abell, 2010), and to effectively implement inquiry-based instruction in their classrooms (Lakshmanan et al., 2011). PLCs can help to create opportunities for teachers to engage in dialogue that makes it safe for them to ask questions, talk about making changes to their classroom practices, and work collaboratively in a community where uncertainty is not only valued, but supported (Snow-Gerono, 2005). Thus, PLCs offer teachers opportunities to be involved in collaborative

Keywords: professional development, teachers' beliefs, research experiences, RET, apprenticeship programs, Learning Communities, inservice teachers

relationships with their peers and have a positive effect on a number of teacher and student outcomes (Akerson et al., 2009; Fazio, 2009; Liu et al., 2010; Vescio et al., 2008). However, with this emphasis on bringing teachers together to talk about classroom practice (Dana & Yendol-Silva, 2003), there is little discussion in the extant research base regarding the extent to which teachers' beliefs and classroom practices about inquiry-based instruction might change following participation in a PLC.

Accordingly, this empirical study sought to advance our knowledge by determining the extent to which teachers' beliefs and classroom practices concerning inquiry-based instruction change following participation in a large mid-Atlantic university's year-long RET-PLC professional development program. It specifically examines how a professional development model combining a summer RET followed by an academic-year PLC focused on translating teacher research experiences to inquiry-based classroom lessons might facilitate changes in science teachers' beliefs and classroom practices concerning inquiry-based instruction. This study further responds to the call made by Capps et al. (2012) for more published research on the effectiveness of professional development models related to inquiry-based instruction.

This research is premised on the view that student learning outcomes are determined in large measure by the nature of students' learning experiences in the classroom. This study makes the assumption that an understanding of the learning experiences that science teachers provide their students cannot be gained apart from an understanding of teachers' beliefs concerning inquiry-based instruction and formal observations of their classroom practices.

Theoretical Framework

A recent review of the literature on apprenticeship programs acknowledged that there is a limited number of empirically-based research studies on RET programs (7 out of 53) for practicing teachers (Sadler et al., 2010). Outcomes of empirically-based studies on in-service RET programs have suggested that extended research experiences promote more robust understandings of scientific ideas and principles and have documented participant perceptions of their own knowledge gains (Boser et al., 1988; Buck, 2003). Furthermore, studies have reported that RET programs foster collaboration and communication among teachers as well as between teachers and scientists as teachers plan their instruction (Dresner & Worley, 2006; Varelas et al., 2005; Westerlund et al., 2002; Yen & Huang, 1998), and bolster participants' confidence to conduct scientific research and/or self-efficacy relative to science (Boser et al., 1988; Dresner & Worley, 2006). Several studies on in-service RET programs have reported mixed outcomes about the transformation of teachers' practices in their classrooms (Boser et al., 1988; Buck, 2003; Dresner & Worley, 2006; Westerlund et al., 2002). Similarly, Blanchard et al. (2009) found that an RET experience can be transformative for teachers, if the teachers come to the experience theoretically ready to learn from it. However, sustained teacher change following a RET requires teachers to rethink their practice at the deepest level, at the level of teachers' beliefs and values. Moreover, Miranda and Damico (2013) found that having in-service science teachers conduct research can help to facilitate changes in their beliefs about their pedagogical practices, and that the successes science teachers experienced during their summer RET program influenced how they planned to teach their own students.

This study is also grounded within a body of literature on PLCs. Recent studies suggest that teacher collaboration leads to increased teacher efficacy when PLCs meet on a regular basis to share and reflect on classroom practices (Chase et al., 2001; Morrison et al., 1994). Additionally, Lakshmanan et al. (2011) found significant growth in the extent to which teachers were able to implement inquiry-based instruction in their classrooms following participation in a PLC. However, empirical studies that investigate how a professional development model that combines having science teachers conduct research with a mentoring scientist and participation in a PLC might impact teachers' beliefs and classroom practices concerning inquiry-based instruction have not been conducted.

The study is framed within a well-established body of literature that affirms the influence of various aspects of teacher thinking about students, and about teaching and learning on classroom practices and learning outcomes (Brickhouse, 1990). Nespor (1987) asserted that beliefs are rooted in personal history and are not easily changed. Pajares (1992) placed beliefs within a group of related constructs that includes attitudes, expectations, values, opinions, perceptions, conceptions, and dispositions. Bryan and Atwater (2002) further proposed that "beliefs are part of a group of constructs that describe the structure and content of a person's thinking that are presumed to drive his/her actions" (p. 823). Thus, it is this relationship between belief and behavior that makes the study of teacher beliefs so critical to an understanding of science education outcomes. Researchers have investigated the effects of teachers' beliefs about the teaching and learning of science (Bryan, 2003), prospective science teachers' beliefs about constructivist teaching practices (Haney & McArthur, 2002), and teachers' beliefs about the nature of scientific content knowledge and teaching and assessment practices (Yerrick et al., 1997). However, empirical studies of how a combined professional development model, a summer RET component followed by an academic-year PLC, can help to transform teachers' beliefs and classroom practices about inquiry-based instruction have not been conducted.

Research Methodology

Research Design Overview and Questions

This mixed-methods study employed a triangulation design (Creswell et al., 2003). The purpose in using this design is to obtain different, but complementary, data on the same topic in order to best understand the research problem (Morse, 1991). The use of this design also brings together the differing strengths and non-overlapping weaknesses of qualitative methods with those of quantitative methods (Patton, 1990). This mixed-methods study was designed to answer the following research questions:

1. What are science teachers' initial beliefs about inquiry-based instruction prior to participation in a year-long RET-PLC professional development program?
2. To what extent do science teachers' beliefs about inquiry-based instruction change following participation in a year-long RET-PLC professional development program?
3. To what extent do science teachers' classroom practices change following participation in a year-long RET-PLC professional development program?

Qualitative methods were used to explore research questions 1 and 2, while quantitative methods were used to explore question 3.

Description of Year-long RET-PLC Professional Development Program Model

Supported with NASA funding, fourteen in-service high school science teachers participated in a large mid-Atlantic university's six-week summer RET program to conduct research under the mentorship of a research scientist. Following the summer RET component, these teachers participated in an academic-year PLC (25 hours) focused on translating teachers' research experiences to inquiry-based lessons in the classroom.

The main objective of the summer RET program was to provide each teacher participant with an opportunity to conduct scientific research under the mentorship of a research scientist. Each potential research mentor provided an overview of his/her research goals and identified at least one project that would be appropriate for a teacher-intern. Teachers selected their top three choices for research placements based on their personal interests and teaching assignments. Each teacher participant was matched to a research project and mentor in a 1:1 ratio based on personal interests, background skills, and current teaching assignment. Prior to the summer research experience, all teachers participated in an orientation meeting at which expectations and requirements for the RET component were reviewed. Teacher participants were also required to meet with their mentor scientist researchers prior to their internships so as to become familiar with the research environment and to discuss internship preparation (e.g., literature review, review of specific laboratory techniques and/or content knowledge). The summer RET program took place between the months of June and August, 2011 and was six weeks in length. The program was designed for teachers to experience various aspects of research, including exploring the literature base for research, designing and conducting experiments, using the tools and techniques of current scientific research, and gaining experience with how scientists use data and accommodate to experimental results that differ from what is expected. Participating mentors agreed that the teachers would be active, contributing members of a research team. Each teacher developed a twenty-minute power point presentation to communicate research findings and implications for school-year instruction to be shared at a research symposium. Teacher participants received monetary stipends for participating in the summer RET program. For their role in the RET program, mentor research scientists were compensated with laboratory materials support.

During the school year following the summer RET component, teachers participated in a Professional Learning Community (PLC). The PLC consisted of six meetings, one monthly from October 2011 to March 2012, ranging from three to six hours in length and totaling 25 hours of direct instructional time. During the PLC, teachers explored various pedagogical topics and STEM education reform initiatives including inquiry-based instruction, formative assessment strategies, effective use of the 5E lesson plan model, educational technologies, integrated STEM instruction, Common Core State Standards, and the *Framework for K-12 Science Education* (2012) (Table 1). Teachers were also provided time to collaborate in content-area groups, sharing progress on lessons they were developing to translate aspects of the summer research experience into engaging classroom instruction. The researchers coordinated all PLC meetings and designed and facilitated approximately 60% of PLC activities. Other institution faculty and staff also facilitated PLC activities. PLC facilitators strived to "teach by example," incorporating and modeling a variety of research-based student-centered learning strategies that participants could readily incorporate into their personal classroom instruction.

Description of Teacher Participants

A total of fourteen high school science teachers from six school districts voluntarily agreed to participate in the year-long RET-PLC professional development program and in this study. The teachers' schools represented a range of achievement levels - five schools were high-achieving, four schools were middle-achieving, and five schools were low-achieving - as evidenced by the State's School Performance Report of 2011 achievement data (Maryland State Department of Education, 2011).

Demographic ranges for participants' schools:

- under-represented minority students enrolled in the schools – 19% - 99%
- classes not taught by "highly qualified" teachers, as defined by the NCLB Act – 3% - 39%
- teachers who possessed alternative/provisional teaching certification – 0% - 7%
- students eligible for free/reduced meals – 10% - 75%
- students passing the state high school assessment in science (biology) – 9% - 54%
- students with an Individualized Education Plan (IEP) – 5% - 29%.

The science teacher participants represented a cross section of the science

Table 1: Academic Year Professional Learning Community Schedule of Activities

Date and Length of Meeting (hours)	Learning Community Activities
October, 2011 (5 hours)	Review of school year programmatic requirements and participation incentives Small group work on lesson plans that translate summer research experiences into inquiry-based classroom activities Exploration of formative assessment strategies (assessment for learning versus assessment of learning) Modeling the implementation of open inquiry in the science classroom Effective use of the 5E lesson plan model
November, 2011 (5 hours)	Exploration of technologies that can be used to enhance science instruction: Using Glogster and blogs for students to develop and communicate science content knowledge Using VoiceThread for digital storytelling Using Screencast-O-Matic for content creation and flipped classroom applications Partner work on how technology can add inquiry and problem solving to classroom lessons
December, 2011 (6 hours)	Analyzing lessons with the Science Teacher Inquiry Rubric (STIR) (Beerer & Bodzin, 2003) Exploring ways to integrate STEM instruction; incorporation of problem-based learning and constructivist philosophy Small group work on lesson plans that translate summer research experiences into inquiry-based classroom activities
January, 2012 (3 hours)	Two participants shared how they have increased the level of inquiry in a recent classroom lesson Modeling the integration of inquiry and science literacy with a focus on asking questions and using evidence to support analysis of scientific text (Common Core Standards for Literacy in Science and Technical Subjects) (National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010) Small group work on lesson plans that translate summer research experiences into inquiry-based classroom activities
February, 2012 (3 hours)	Two participants shared how they have increased the level of inquiry in a recent classroom lesson Small group work on lesson plans that translate summer research experiences into inquiry-based classroom activities Modeling how to teach the components of experimental design in a more student-centered engaging way
March, 2012 (3 hours)	Two participants shared how they have increased the level of inquiry in a recent classroom lesson Program Exit Surveys Modeling the implementation of a guided inquiry lesson Small group work on lesson plans that translate summer research experiences into inquiry-based classroom activities

disciplines taught in high school, e.g., anatomy and physiology, biology and AP biology, chemistry and AP chemistry, earth science, ecology, forensics, health, marine biology, microbiology, and physics and AP physics. Five of the fourteen teachers had prior research experience beyond what is characteristic of undergraduate-level science classes. Three of these teachers had Ph.D.s in scientific fields of study; one had five years combined undergraduate and graduate research assistantship experience; and one had worked in the research and development division of a construction materials company for approximately ten years. Table 2 provides profiles of the study participants with respect to their gender, teaching experience, and level of education. Table 3 provides profiles of the study participants with respect to research area for the RET, prior research experience, and course(s) and grade level(s) taught. Thirteen of the fourteen teachers had advanced professional teaching certification, while one teacher had a standard professional teaching certification. Table 4 provides a brief description of the teachers' summer RET research projects.

Data Collection

The sources of data for this study were 1) teachers' pre-participation essays that focused on teachers' initial conceptions of inquiry-based instruction, 2) on-line researcher-facilitated asynchronous threaded discussion board post transcripts, 3) pre-participation and post-participation classroom lesson observations, and 4) post-observation open-ended questionnaires (pre-participation and post-participation) that allowed participants an opportunity to reflect on their teaching and describe how they implemented inquiry in their observation lessons.

Pre-participation essays. Prior to participating in the program, each teacher submitted an essay explaining his/her perception of how inquiry or inquiry-based learning is important to students' educational experiences and describing a specific example of how he/she uses inquiry or inquiry-based instruction in the classroom.

Transcripts of asynchronous threaded discussion board posts. The year-long RET-PLC professional development program's asynchronous discussion board was designed by the researchers to create a collaborative learning environment, as described by Cox and Cox (2008), which develops interpersonal and group dynamics. Throughout the summer RET, all teacher participants were required to post weekly contributions to

Table 2: Participant Profiles: Gender, Teaching Experience, and Level of Education

Pseudonym	Gender	Teaching Experience	*Level of Education*
Michelle	Female	10	M.A.
Carly	Female	7	Ph.D.
Laura	Female	12	M.A.
Kathy	Female	6	M.A.
Bonnie	Female	12	Ph.D.
Angie	Female	6	M.A.
Denise	Female	18	M.Ed.
Paula	Female	19	M.A.
Jackie	Female	6	Ph.D.
Mark	Male	9	M.A.
Rick	Male	4	M.A.
Stan	Male	19	M.A.
Rose	Female	11	M.A.
Vicky	Female	16	M.A.

Table 3: Participant Profiles: Research Area for RET, Prior Research Experience, and Course(s) and Grade Level(s) Taught

Pseudonym	Research Area For RET	Prior Research Experience	*Course(s) and Grade Level(s) Taught*
Michelle	Bioscience	No	Biology, AP Biology, Ecology; 9-12
Carly	Chemistry	Yes	Chemistry; 10
Laura	Bioscience	No	Biology, Forensics, Marine Biology; 10-12
Kathy	Bioscience	No	Biology, Anatomy and Physiology; 9, 11-12
Bonnie	Bioscience	Yes	AP Biology, Anatomy and Physiology; 9, 11-12
Angie	Bioscience	No	Chemistry, Pre-Chemistry; 10-12
Denise	Physics	Yes	Physics, 11-12
Paula	Bioscience	No	Biology, Microbiology; 9-12
Jackie	Bioscience	Yes	Science and Sustainability, Health; 9-12
Mark	Bioscience	Yes	Biology, AP Biology; 10, 12
Rick	Bioscience	No	Biology; 10-12
Stan	Physics	No	Honors Physics, AP Physics; 11-12
Rose	Bioscience	No	Chemistry, AP Chemistry; 10-12
Vicky	Bioscience	No	Biology, AP Biology; 10-12

an on-line, password-protected, researcher-facilitated asynchronous, threaded discussion board. Following the summer RET from September 2011 to March 2012 teachers were required to participate in a discussion board forum once a month as a follow-up to that month's PLC meeting.

The asynchronous threaded discussion board was designed to enhance interaction among teacher participants from different research locations and allow them to communicate, network and share experiences about their respective scientific research projects (Cox and Cox, 2008). The questions posted on the asynchronous threaded discussion board were formulated by the researchers in relation to the study's research questions to encourage participants to reflect on their own experiences as learners, their students' learning experiences in the classroom, and pedagogical practices that might help to promote student engagement with science. Moreover, researchers posted probing questions on the asynchronous threaded discussion board as needed to clarify participants' meanings and to ask participants for concrete examples to substantiate their espoused beliefs when relevant. All asynchronous threaded discussion board transcripts were collated and saved electronically.

Pre-participation and post-participation classroom lesson observations. The Reformed Teaching Observation Protocol (RTOP) instrument (Sawada et al., 2002) was used (pre-participation and post-participation) to collect quantitative data to describe teachers' use of an inquiry-based instructional approach, and to document if/how teachers' classroom practices changed after they participated in the year-long RET-PLC professional development program. The RTOP is a 25-item observation protocol containing seven subscales (Lesson Design and Implementation, Content Total, Content: Propositional Knowledge, Content: Procedural Knowledge, Classroom Culture Total, Classroom Culture: Communicative Interactions and Classroom Culture: Student/Teacher Relationships). The protocol enables researchers to rate a teacher's degree of reformed teaching using a 5-point Likert-type scale from 0 (never occurred) to 4 (very descriptive). Sawada et al. (2002) established the inter-rater reliability of the RTOP instrument using a linear regression of independent observations by paired trained raters, $r = 0.98$. The Cronbach alpha for the RTOP instrument as a whole was 0.97 (Sawada et al., 2002) showing a high degree of internal consistency across items. Subscale alphas were also high, despite the fact that each consisted of only five items, and ranged from 0.80 to 0.93 (Table 6) (Sawada et al., 2002). The RTOP subscales were used in this study because of their wide use and acceptance in the science education research community (Yezierski & Herrington, 2011). Each teacher was observed teaching a self-chosen lesson in his/her classroom by two researchers who were trained to use the RTOP instrument. Following each observation, the researchers met and determined a consensus score for each item on the RTOP instrument.

Post-observation open-ended questionnaires. After each classroom observation (pre-participation and post-participation teaching), each teacher responded to an open-ended questionnaire that included questions about what was successful in the lesson, how the learning was assessed, how inquiry was included in the lesson and how the lesson could be improved for future implementation.

Data Analysis

Qualitative data analysis. All qualitative data collected were analyzed by two researchers. An inductive analysis approach (Corbin & Strauss, 2008) was used to evaluate and categorize teachers' pre-participation essays, researcher-facilitated asynchronous threaded discussion board post transcripts, and responses to post-teaching observation open-ended questionnaires. The purpose for utilizing this type of approach was (1) to condense extensive and varied raw text data into a brief, summary format, (2) to establish clear links between the research objectives and the summary findings derived from the raw data, and (3) to develop a model or theory describing the underlying structure of experiences or processes that are evident in the raw data. The inductive approach reflects frequently reported patterns used in qualitative data analysis and is used when researchers are examining data for emergent patterns or themes (Thomas, 2003). Moreover, with this approach the research findings result from multiple interpretations made from the raw data by the researchers who coded the data

Table 4: Teachers' Summer RET Research Projects: Brief Description of Research Project

Pseudonym	Description of Summer RET Research Project
Michelle	Using microdialysis to investigate the effects of drugs of abuse and potential medications on brain neurotransmitter concentration
Carly	Application of EPR spectroscopy to study organic spin-labels in liquid inclusions within single crystals to model cellular environments
Laura	Use molecular and cellular biology techniques to study the molecular and genetic regulation of muscle cell differentiation
Kathy	Use cellular and molecular biology techniques to study the expression of cancer antigens in order to find potential treatments or therapies
Bonnie	Use crystallization or fluorescence techniques and small-angle x-ray scattering to study function of DNA repair enzymes
Angie	Use protein purification and isotherm titration to study regulatory functions of calcium-binding proteins
Denise	Use vacuum technology and cryogenics to study electronically active interfaces in thin films of metal oxides
Paula	Use various molecular and cellular biology techniques to explore the growth and metabolism of a halophilic microbe
Jackie	Perform analyses including measurements with a microplate reader and GC-MS in order to quantify alkyl nitrates produced by phytoplankton
Mark	Investigate how environmental conditions affect gut microflora communities and wood-eating capabilities in catfish
Rick	Use various cell and molecular techniques to confirm the expression level of certain proteins in normal and cystic fibrosis cells
Stan	Use vacuum technology and cryogenics to study electronically active interfaces in thin films of metal oxides
Rose	Use molecular cellular biology techniques are used to study the growth of mutant yeast strains under various conditions
Vicky	Use cellular and molecular biology techniques to test the effects of novel mitochondria associated proteins on mitochondrial structure and function

and are shaped by the assumptions and experiences of the researchers conducting the research and carrying out the data analyses.

In this study, the primary mode of inductive analysis was the development of categories from raw data into a model or framework that captured key themes and processes judged to be important by the researchers. The categories that emerged from the data provided the researchers with a general sense of reference among the data set. The researchers then used the categories as tools to see similarities and differences in the varied perceptions of the teachers participating in the year-long RET-PLC professional development program. Relationships between core categories were sought and tested both within and across the qualitative data set by two researchers. Codes and categories were also sorted, compared and contrasted until analysis produced no new codes or categories, and until all of the data were accounted for in the core categories. Data collection and data analysis occurred concurrently, with the results of early analyses being used to inform subsequent data collection in an iterative manner. The emerging patterns or themes were formulated in relation to research questions 1 and 2.

Quantitative data analysis. Quantitative methods were used to explore research question 3. The Wilcoxon matched-pair signed-rank test was employed in this study to evaluate a one-group pretest-posttest design. Using SPSS, a Wilcoxon matched-pair signed-rank test was conducted to analyze the data (pre-participation and post-participation) for study participants' total RTOP score, and the five RTOP subscale scores (Lesson Design and Implementation, Content: Propositional Knowledge, Content: Procedural Knowledge, Classroom Culture: Communicative Interactions and Classroom Culture: Student/Teacher Relationships). The Wilcoxon matched-pairs signed-rank test is a nonparametric method to compare before-after, or matched subjects, and is often used to determine the magnitude of difference between matched groups of paired data (Hinkle et al., 2002). In this study, the Wilcoxon matched-pair signed-rank test specifically assessed whether this population of teachers' classroom practices as evidenced by their RTOP observation scores differed before and after their participation in a year-long RET-PLC professional development program. Thus, the null hypothesis for this study is that there is no difference in teachers' classroom practices as evidenced by their RTOP observation scores before and after participation in a summer RET followed by an academic-year PLC. Two-tailed significance was reported since the directionality of deviation from the null hypothesis was not predictably in one direction prior to data collection or analysis. The significance level reported throughout this study is 0.05.

Findings

In addressing the first research question, the themes that emerged from the pre-participation data regarding teachers' initial beliefs about inquiry-based instruction were: impact on students, questioning and communication, teacher-centered instruction, student-centered instruction, and difficulties incorporating inquiry-based instruction (Table 5).

Impact on Students

Without exception, all teachers believed that inquiry-based instruction is essential in developing critical thinking skills and problem solving abilities in their students. For instance, Darlene expressed, "Inquiry-based instruction is crucial in developing critical thinking skills, such

Table 5: Qualitative Data: Teachers' Initial Beliefs About Inquiry-Based Instruction

Themes	Core Categories
Impact on Students	a) Develop students' critical thinking skills and problem solving abilities b) Conduct hands-on laboratory activities to experience science while learning science content c) Valuable for students taking upper-level science courses associated with high-stakes tests (e.g., AP Biology) d) Social aspect of inquiry-based instruction (e.g., student-student interactions, case studies, group questioning, vocabulary activities)
Questioning and Communication	a) Posing questions or problems to students and having them answer them b) Questions based on topics that students are familiar with c) Use of Socratic methods (e.g., ask students lots of probing questions; discuss and communicate responses)
Teacher-Centered Instruction	a) Demonstrate to students how to set-up and solve problems b) Prep students with relevant vocabulary c) Review and discuss drills and guided notes d) Complete handouts e) Conduct cookbook labs
Student-Centered Instruction	a) Teachers posing a research question to students and instructing them to design the procedures and develop conclusions using data sets b) Students designing their own experiments c) Students posing and answering questions d) Students testing their predictions/hypotheses
Difficulties Incorporating Inquiry-Based Instruction	a) Perceived time constraints due to high-stakes testing b) Unfamiliarity with how science is practiced c) Inadequate resources or preparation in science d) Did not understand or know how to facilitate inquiry-based instruction

as manipulating laboratory equipment, analyzing data and drawing conclusions." Similarly, Bonnie articulated, "Inquiry-based learning allows the students to formulate their own knowledge and develop problem-solving skills." Likewise, Carly explained, "Students who actively make observations, collect, analyze and synthesize the information and develop conclusions through the different classroom applications develop useful problem solving skills along with study skills." Laura further stated, "Inquiry-based learning activities are vital for students because they relate directly to the types of problem-solving activities that are at the heart of science education."

In order to develop critical thinking skills and problem solving abilities in their students, a couple of teachers (2 out of 14) explained that they needed to develop challenging inquiry-based activities. For example, when describing an inquiry-based activity that she developed, Martha expressed, "Although there is a cookie-cutter lab spelled out for teachers to use in the lab book, I have chosen to stray from it to better challenge my students to create their own lab." Similarly, when describing a challenging inquiry-based laboratory activity where her students had to build a structure out of paper and tape that delays the decent of a ball, Darlene explained, "As they go through the construction process they need to be thinking about how time, distance, and speed are related and how they can affect these variables with their construction methods."

Prior to participating in the RET-PLC program, the majority of teachers (10 out of 14) also believed that inquiry-based instruction meant having students conduct hands-on laboratory activities as a way to experience science while learning science content. For example, Stan commented, "The best part of a physics course is where my students will be doing a laboratory activity," and further expressed "this is the heart of inquiry based learning." However, participants had mixed responses regarding whether teachers should provide their students with laboratory procedures, or whether teachers should allow their students to develop laboratory procedures themselves. For instance, when describing an inquiry-based laboratory activity that she conducted with her students on the measurement of enzymatic activity, Bonnie articulated that she "provided students with a method to measure the activity of catalase." In contrast, Rick expressed, "My students designed procedures and carried out experiments for the catalase activity and designed investigations to test which factors affect the rate of photosynthesis in plants."

One teacher (Bonnie) remarked that an "inquiry-based approach is extremely valuable for students when taking the AP Biology test, because each year, one of the four essays requires experimental design or analysis." Another teacher (Kathy) focused on the social aspect of inquiry-based instruction and expressed, "Inquiry-based instruction is having students work together collaboratively using cooperative groups and other strategies (case studies, group questioning, vocabulary activities) to foster group interaction."

Table 6: Change in Teachers' Classroom Practices as Observed by the RTOP

RTOP Subscale and Total RTOP scores	Cronbach Alpha	*p*-value	*Decision*
Lesson design and implementation	0.91	0.054	Retain the null hypothesis
Content: Propositional knowledge	0.80	1.000	Retain the null hypothesis
Content: Procedural knowledge	0.93	0.220	Retain the null hypothesis
Classroom Culture: Communicative interactions (student-student)	0.91	0.013	Reject the null hypothesis
Classroom Culture: Student/teacher relationships	0.91	0.016	Reject the null hypothesis
Total RTOP score	0.97	0.028	Reject the null hypothesis

Questioning and Communication

The majority of teachers (10 out of 14) believed that posing questions or problems to students and having them answer those questions was the most essential features of inquiry-based instruction. For instance, Jackie explained that "science by its very nature is inquiry-based; you pose scientific questions and find the best means to answer those questions." Similarly, Carly expressed, "Inquiry-based instruction is mainly getting students involved through questions, which leads to understanding." When encouraged to reflect on the lesson that they were observed teaching prior to participating in the RET-PLC professional development program, several teachers (5 out of 14) mentioned that they incorporated inquiry by using teacher-led questioning methods. These teachers explained that they would ask students lots of probing questions and allow them to discuss and communicate their responses with the rest of the class. Teachers further indicated that the questions they posed to students were generally based on topics that students were familiar with so that they could make the content more relevant to them.

Teacher-Centered Instruction

When reflecting on their classroom teaching prior to participating in the RET-PLC professional development program, almost half of the teachers (6 out of 14) described their lessons as utilizing a teacher-centered approach. When asked to further describe how they incorporated inquiry into their lessons, these teachers articulated that they typically: demonstrate to students how to set up and solve problems; prep students with relevant vocabulary; review and discuss drills and guided notes; complete handouts; and conduct cookbook labs where they provide the question and procedures to students. For instance, Jackie expressed, "I use inquiry-based learning everyday in my science classroom, where my students conduct experiments following scientific procedures outlined for them." Similarly, Carly articulated, "I usually start a topic by demonstrating a reaction." Likewise, Mark explained, "I have used inquiry-based learning on numerous occasions to help reinforce the understanding of biology concepts."

Student-Centered Instruction

Some teachers (4 out of 14) described how they incorporated inquiry in their lessons by posing a research question to their students and instructing them to design the procedures and develop conclusions using data sets. For instance, Bonnie expressed that her "students are expected to design experiments to test the effect of substrate concentration on enzyme reaction rate." Laura similarly explained, "I use inquiry as a means to introduce experimental design and to get my students to outline the basic steps of how to design a good science experiment." Rose stated, "Instead of being spoon-fed answers or copying notes and filling in blanks without thinking, students need to pose and answer questions during the process of scientific investigations." Mark explained, "I allow students time to create an experiment and to test their prediction/hypothesis." Mark further articulated, "At the end of the lab period, the students are asked to state whether their predictions were correct or incorrect and to explain why."

Difficulties Incorporating Inquiry-Based Instruction

The majority of teachers (10 out of 14) further communicated several difficulties concerning incorporating inquiry-based instruction, including perceived time constraints due to high-stakes testing, unfamiliarity with how science is practiced, inadequate resources or preparation in science, or lack of understanding of how to facilitate inquiry-based instruction. For example, Jackie described having difficulty "getting students to pose related questions and design experiments to answer those questions." Similarly, Mark expressed, "I don't believe that simply giving students an inquiry task to self-discover and construct their knowledge is effective because the students may not correctly understand the scientific concept, which may lead to the development of a misconception."

In addressing the second research question, there are several changes in teachers' beliefs about inquiry-based instruction that emerged from the post-participation data. Almost half of the teachers (5 out of 14) shifted in their beliefs about inquiry-related classroom practices, moving from a teacher-centered approach to either a structured or guided inquiry-based approach. More specifically, after participation in the summer RET, some teachers (4 out of 14) described their plans to modify their confirmation or structured cookbook-type activities and develop them into higher-level guided or open inquiry-based investigations. They attributed changes in their beliefs about their pedagogical approach to their own successful learner-centered summer research experiences as well as to the collaborative nature of their work with their mentor research scientists. For example, Rick expressed, "I am gradually giving my students more freedom to design experiments and carry them out in their own way." Similarly, Angie stated, "My research work has strengthened my lab skills tremendously and after returning back to school I will be focusing more on open inquiry labs instead of cookbook labs." Stan also explained, "I am trying to collect as much raw data as possible so I can let my students figure out what all those little experimental differences mean." Similar to the supportive relationship with her summer research mentor, Martha stated, "I will make it a point to be sure that my students feel safe to ask questions that pop into their head as we proceed through the year." A few teachers (3 out of 14) mentioned plans to make science content more realistic, relevant and rigorous for their students in the upcoming academic year.

Although these teachers shifted their beliefs about their instructional approach and intended to increase the level of inquiry incorporated into their lessons, they often responded on their post-participation, post-teaching observation questionnaire that they did not provide an adequate amount of time for students to conduct experiments. Consequently, their students were not typically provided with opportunities to communicate or discuss what they had learned based on evidence. Moreover, all teachers described on their post-participation, post-teaching observation questionnaire that they provided their students with questions for them to investigate in class. Furthermore, some teachers (5 out of 14) that taught math-laden and higher-level (honors/AP) science courses retained their initial beliefs about utilizing a teacher-centered approach. These teachers maintained their belief that posing questions or problems to students and having them answer them is the most essential feature of inquiry-based instruction. Likewise, teachers teaching physical science-type courses (e.g., physics or chemistry) retained their initial approach of having students conduct cookbook labs or activities where procedures are provided to students.

Changes in Classroom Practices

In addressing the third research question, significant differences (0.05 level of significance) in teachers' classroom practices following the year-long RET-PLC PD program were observed (Table 6), including teachers' total RTOP score (p=0.028), as well as the two Classroom Culture subscales - Classroom Culture: Communicative Interactions (Student-Student Interactions) (p=0.013) and Classroom Culture: Student/Teacher Relationships (p=0.016). However, there were no significant differences in teachers' classroom practices regarding Lesson Design and Implementation (p=0.0547) or either Content subscale - Content: Propositional Knowledge (p=1.000) or Content: Procedural Knowledge (p=0.220) - following participation in the year-long RET-PLC PD program.

Although teachers' overall Lesson Design and Implementation subscale score did not change significantly after participation in the RET-PLC PD program, teachers did increase the frequency with which student exploration of science content and concepts preceded formal explanation. In their post-participation classroom observations, teachers also more frequently allowed student input into the focus and direction of their lessons.

There was no significant difference between the teachers' pre- and post-program Propositional Knowledge (p=1.000) (Table 6). However, teachers did increase the frequency with which connections with other content disciplines and/or real-world phenomena were explored and valued. Overall, teachers did not significantly increase their use of reformed-teaching practices associated with Procedural Knowledge (p=0.220) (Table 6). However, when examining change in specific Procedural Knowledge RTOP items, teachers provided more opportunities for their students to be reflective about their learning and increased the intellectual rigor of their post-participation lessons, including encouraging constructive criticism and valuing the challenging of ideas.

Classroom observations showed significant increases in teaching practices related to both Communicative (Student-Student) Interactions (p=0.013) and Student/Teacher Relationships (p=0.016) (Table 6). More specifically, after their participation in the RET-PLC program, teachers increased their encouragement and value of active student participation, were more patient with their students, and better represented the metaphor "teacher as listener" during their classroom instruction.

Four RTOP items – the lesson was designed to engage students as members of a learning community, there was a climate of respect for what others had to say, active participation of students was encouraged and valued, and teacher acted as a resource person, working to support and enhance student investigations – showed transition from teacher-centered to student-centered practices, i.e., increasing to an average of 2 or better on the RTOP (MacIsaac & Falconer 2002). Overall, teachers improved their Student/Teacher Relationships RTOP subscale score from a teacher-centered to a reform-oriented level of practice (p=0.016) (Table 6).

Discussion and Conclusion

In contrast to existing studies, the findings of this study are distinctive in that they describe how a professional development model combining a summer RET followed by an academic-year PLC focused on translating teacher research experiences to inquiry-based classroom lessons might facilitate changes in science teachers' beliefs and classroom practices concerning inquiry-based instruction. Thus, the study's findings contribute to the research literature base and have several implications for developers of professional development programs for in-service science teachers as well as for science education researchers.

An important finding of this study is that a summer RET augmented by an academic-year PLC can help teachers to shift their beliefs about their classroom instruction. However, after participation in the RET-PLC program, only half of the teachers (7 out of 14) shifted in their beliefs about their instructional practices from a teacher-centered approach to a more structured-inquiry or guided-inquiry approach. This outcome is consistent with the findings of other researchers who have reported mixed outcomes in the transformation of teachers' beliefs and practices in their classrooms (Boser et al., 1988; Buck, 2003; Dresner & Worley, 2006; Westerlund et al., 2002).

Another finding of this study is that most of the teacher participants who taught math-laden and higher-level (honors/AP) science courses retained their initial beliefs about utilizing a teacher-centered approach in their classroom practices. These teachers maintained their belief that posing questions or problems to students and having them answer/respond was the most essential feature of inquiry-based instruction. Additionally, most of the teacher participants teaching physical science-type courses (e.g., physics or chemistry) retained their initial approach of having students conduct cookbook labs or activities. These research findings are unique and were not evident in the extant research literature base. Although studies on RETs have been shown to benefit teachers of any science content area, teachers of certain science disciplines may experience more difficulty translating inquiry-based research experiences to classroom practices. Therefore, the possibility that RET-PLC programs might be more effective if they were developed to target specific science content areas warrants further investigation by science education researchers.

This study also found that after participating in an RET-PLC professional development program, high school science teachers made significant changes in their classroom practices as evidenced by their total RTOP score and two of the five

RTOP subscale scores. After participating in the RET-PLC program, teachers in this study more frequently encouraged and valued the active participation of students, were more patient with their students, and more often demonstrated the metaphor "teacher as listener" in their lessons. This exclusive finding was not evident in the research literature base. When examining teaching practices associated with Classroom Culture, teachers improved their Student/Teacher Relationships subscale score to a reformed level of practice, shifting their classroom practices from a teacher-centered to a student-centered approach. These changes in teachers' classroom practices are promising because providing a positive classroom environment where students' active participation is valued and the teacher is more of a "guide on the side" is essential to facilitating inquiry-based instruction. Furthermore, maintaining a classroom culture where students feel encouraged to share their view points, including ideas about experimental procedures and potential interpretations of data, and empowered to conduct their own investigations, is critical to accomplishing the active, student-centered instructional approach promoted by National Science Education reform initiatives (National Research Council, 2012).

It is important to note that although significant differences were observed in other classroom practices following participation in the RET-PLC program, half of the teachers (7 out of 14) in this study are still not implementing these practices in a reformed, student-centered way. This outcome concurs with the recommendation of Blanchard et al. (2009) that transformative professional development will require teachers to rethink their practice at the deepest levels, at the level of teachers' beliefs and values. Thus, in order to effect more meaningful changes in teaching practices, teachers may need extended time to reflect on how their beliefs about reform-oriented inquiry-based instruction could be better manifested in their actual classroom practices. In addition, in order to facilitate the implementation of higher-level inquiry instruction, time must be built into science curricula for these learning experiences. This time could be in the form of teaching fewer lessons with greater depth, affording more opportunities for students to design their own investigations and construct their own learning about science content.

In their study of K-12 science and mathematics teachers' beliefs about and use of inquiry in the classroom, Marshall et al. (2009) found that the time allocated for inquiry decreases significantly for science teachers as the grade level increases. They propose that high school science teachers might lack the pedagogical knowledge to implement inquiry effectively at this level or may view inquiry-based learning as an inefficient format, especially for transmitting knowledge needed by students to be successful on tests (Marshall et al., 2009). Thus, the role of testing and examination in relation to classroom curricula could be an important reason for teachers in higher-level science courses not to change their practices. The findings of this study provide evidence that an RET-PLC program that models inquiry-based learning for teachers and provides support for them to plan and implement inquiry-based instructional strategies in their classrooms can positively impact high school science teachers' beliefs about inquiry-based instruction and their use of reformed-teaching practices. Teachers in this study increased their use of reformed-teaching practices, such as providing more opportunities for students to explore science content prior to explanation, encouraging and valuing active student participation, and exhibiting "guide on the side" teaching characteristics. These results can help to support the goals of several of *A Framework for K-12 Science Education*'s Scientific and Engineering Practices (National Research Council, 2012) and demonstrate that an RET-PLC professional development program model can improve teachers' ability to facilitate lessons in which students independently develop their content knowledge by engaging in the practices of science.

Implications for Science Teacher Professional Development

The findings of this study have several implications for designing effective professional development programs for science teachers, including how professional development programs should incorporate the current recommendations of science education reform (National Research Council, 2012). Transforming beliefs about science education reform initiatives into measureable classroom practices, for example increasing teachers' implementation of inquiry-based instruction in the classroom, is a significant step toward increasing student engagement in science as well as student performance in science courses. The findings of this mixed-methods study therefore advance our knowledge in the research base regarding how an RET-PLC professional development program can impact the classroom practices of teachers.

Loucks-Horsely et al. (2010) stress that long-term, sustained professional development has the potential to effect more significant change in teaching and learning. Even though our RET-PLC program was a year in length, for the most part we did not see changes in classroom practices demonstrating that teachers had transitioned from the use of teacher-centered to reform-oriented practices. These findings may imply that more time is needed for teachers to fully embrace a student-centered inquiry-based instructional philosophy. Alternatively, despite participating in a year-long RET-PLC program, several HS science teachers may still be resistant to using reform-oriented teaching practices, especially if they teach higher-level science courses or physical science courses that rely heavily on mathematics. Thus, an examination of the effects of extended professional development or follow-up post-programs to monitor teaching practices warrants further investigation by science education researchers.

Our study's finding that a year-long RET-PLC program did not significantly change teachers' classroom practices regarding lesson Content suggests that future in-service teacher professional development should be designed to help science teachers more effectively plan lessons that promote strongly coherent conceptual understanding, encourage and value elements of abstraction when it is important to do so, and provide students with opportunities to make predictions, devise means for testing them and actively engage in the critical assessment of procedures. This study's findings also suggest that future in-service science teacher professional development should provide guidance and support for teachers of math-laden, higher-level, or physical science type courses to implement more student-centered learning experiences that can promote student engagement with science. Moreover, the findings reveal that future in-service professional development should be designed to help science teachers more effectively plan opportunities for students to be engaged in inquiry-based activities, including opportunities for them to develop questions to investigate for themselves and to communicate findings that are based on evidence, especially evidence gathered during their own investigations.

Limitations of the Study

One limitation of the study is that the participants may be viewed as highly-motivated and experienced, and thus not representative of "typical" classroom teachers. Moreover, federally funded-RET program participants tend to be better educated than the average K-12 teacher in that 64% had at least a master's degree and 7% had a doctorate (comparable K-12 teachers nationwide were 47% and 1%, respectively), and averaged about 12 years of teaching experience (National Science Foundation, 2007). Thus, the transferability of the findings of this study to other settings will need to be judged as the reader examines the results in the context of specific circumstances of interest. Also, it is important to note that due to the small sample size (N=14) of this study, there is the potential that a few responses could change the results of our investigation. Another potential limitation regarding the interpretation of the results of the study is that each study participant's teaching practices were measured only twice using the RTOP instrument (pre-participation and post-participation). Additionally, teachers in this study were free to choose when the researchers observed them teaching both prior to their participation in the program and after, including the time of day, the specific course, and the achievement level of the class. We did not provide instructions to the teachers regarding the content or nature of their classroom observations, i.e., we did not instruct them to implement their best inquiry-based lesson either prior to or after their participation in the PD program. We believe it was especially important to give the teachers full choice on what type of lesson they taught during their post-program observation, eliminating the researchers' influence on whether or not teachers chose to demonstrate instructional knowledge gained during the program. This allowed the researchers to observe, if given the choice, whether or not teachers would actually implement a higher-level, inquiry-based lesson. Furthermore, two of the teachers in the study chose to focus on scientific literacy skills for their post-program classroom observation. Thus, those lessons that taught skills related to reading a scientific paper or using context clues to derive meaning of vocabulary terms did not result in high scores on some items on the RTOP instrument. Moreover, lessons in which students conducted experimental laboratory activities tended to result in higher scores on some items on the RTOP instrument. Future research studies utilizing the RTOP instrument as a measure of inquiry-based classroom practices should be mindful of these limitations.

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Rommel J. Miranda, Ph.D., Associate Professor of Science Education, Department of Physics, Astronomy & Geosciences, Towson University. Dr. Miranda is the director of the "Blinded by the Light: Urban K-12 Portable Planetarium Outreach Program," co-director of the National "Project ASTRO" institutional site in Towson, Maryland, Regional Director for the Mid-Atlantic Association for Science Teacher Education, and co-Editor of the National/International Association for Science Teacher Education Newsletter. Correspondence concerning this article should be sent to: Dr. Rommel J. Miranda, Department of Physics, Astronomy & Geosciences, Towson University, 8000 York Road, Towson, Maryland 21252. Email: Rmiranda@towson.edu

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Julie B. Damico is the Director of the Baltimore Excellence in STEM Teaching Project, a professional development program for in-service secondary STEM teachers coordinated through Towson University's Fisher College of Science and Mathematics.

Acknowledgements: We would like to formally acknowledge and thank the National Aeronautics and Space Administration (Grants: NNX09AT03G; NNX10AJ68G) for supporting our program and research.