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Transitioning to Inquiry-Based Teaching: Exploring Science Teachers' Professional Development Experiences

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Abstract

The literature on professional development is replete with studies that utilize survey, interview, and classroom observation data, primarily collected post professional development experience, to explore teachers' knowledge, beliefs, and actions; however, we lack a clear understanding of teachers' learning process and reflections during the professional development. The current study aims to address the abovementioned gaps in the literature, by utilizing participant reflections and assignments during a summer professional development opportunity, to elucidate the process by which teachers learn about inquiry-based teaching and begin to implement it in their planning, in addition to factors they deem influential in this process. The findings address three questions about professional development: 1) participants' process of developing professionally, 2) features of effective professional development, and 3) the relationship between participants and the program. Furthermore, a web of interrelationships is revealed between participant-identified beneficial programmatic features and the participants' experiences, processes of personal, social, and professional development, evolving conceptions and beliefs, and the translation of these beliefs into practice, as evident in their immediate implementation of ideas in instructional planning.

Keywords: beliefs, Professional Development, inquiry, in-service teacher education, teaching practices

Introduction

Despite repeated calls by the science education community and the emphasis of national science education policy documents (NRC, 1996; NRC, 2012) on inquiry-based teaching, we continue to witness a fairly slow progress in this direction. According to the math and science education survey by Weiss, Banilower, McMahon, and Smith (2001), classroom science instruction continues to be dominated by teacher-centered instruction, direct transmission of knowledge, and an overemphasis on rote memorization of content. Teachers play an indisputably decisive role in the success and implementation of reforms (Duschl, 1990; Lumpe, Haney, & Czemiak, 2000). Teachers' beliefs, knowledge, and experiences and the interrelated effect of these on their instructional decisions (Van Oriel, Beijaard, & Verloop, 2001) considerably impact the attainment of reform goals.

Successfully adopting an inquiry-based approach to teaching and learning in a classroom requires that teachers be familiar with both the nature of scientific inquiry and inquiry-based learning and implement such practices in their classrooms (Anderson, 2002). However, countless teachers are unable to effectively employ inquiry-based instructional methods because this approach to teaching is an abstract idea to them. They did not encounter it in their own K-12 education nor experience it during their training and preparation in becoming teachers (Kazempour, 2009). Hence, making the shift to an inquiry-based approach to teaching science could be a "daunting task" that teachers struggle to undertake (Bonner, Letter, & Harwood, 2004).

In an effort to remedy this issue, science education reform documents (e.g. NSES) have hailed inquiry-based professional development (PD) as a significant tool in facilitating science teachers' adoption and implementation of inquiry-based planning, assessment, and instructional beliefs and practices. As stated by Supovitz and Turner (2000), "The implicit logic of focusing on professional development as a means of improving student achievement is that high quality professional development will produce superior teaching in classrooms, which will, in turn, translate into higher levels of student achievement" (p. 965). The PD literature is continuously growing to address the considerable gaps existing within this branch of research. One area that deserves further attention is teachers' learning experience during a PD program, the evolution of their beliefs and understanding throughout the PD, and the immediate application of PD ideas in their instructional decisions. The aim of the current study is to explore high school science teachers' written reflections and assignments during an inquiry-based PD opportunity to elucidate the process by which they learn about inquiry-based teaching and the extent and scope of their adoption and application of such ideas, as evident in their immediate implementation of ideas in their instructional planning.

Theoretical Framework

Over the past two decades, PD programs for in-service primary and secondary teachers of science have grown substantially. Science education documents such as the NSES and the NSTA position statement (2006) have highlighted the urgent need for and effective means of achieving professional development for teachers.

A number of studies (e.g. Huskey, 2003; Loucks-Horsley, Love, Stiles, Mundry, and Hewson, 2003) focusing on the critical features of PD have suggested designing long-term, research-based PD experiences, which provide teachers opportunities for collaborating within a community of peers. Furthermore, it is critical that teachers gain an enhanced understanding of content (Jeanpierre, Oberhauser, & Freeman, 2005) and pedagogy as they undergo a transformative experience that will, (1) provide them with a "well defined image of classroom learning and teaching" (Loucks, et al., 2003), (2) actively engage them in the learning process, and (3) provide teachers with opportunities to "experience sufficient dissonance to disturb existing beliefs, knowledge, experiences with learning and teaching" (Thompson & Zeuli, 1999, p. 355). As suggested by Darling-Hammond and McLaughlin (1995), "Teachers learn by doing, reading, and reflecting (just as students do)... To understand deeply, teachers must learn about, see, and experience successful learning-centered and learner-centered teaching" (p. 598). A final critical feature of successful PD is the creation of a support system for teachers, including continued communication with and support from the PD facilitators and participants as well as organizational support from school administrators, in order to alleviate teachers' implementation of workshop ideas (Kazempour, 2009; Banilower, Heck, & Weiss, 2007).

Thompson and Zeuli (1999) suggest that a critical component of effective PD is the evaluation of such experiences. A number of studies have explored this question by focusing on one or more of the following: teachers' content knowledge, teachers' beliefs and core conceptions, teachers' classroom practices, and student outcomes. Fewer studies (e.g. Lehman, George, Rush, Buchanan, & Averill, 2000; Luft, 2001) have concentrated on the impact of teacher PD on student outcomes; however, the impact on teachers' content knowledge, beliefs, and classroom practices are speculated to subsequently affect student attitudes and learning (Supovitz & Turner, 2000).

Supovitz and Turner utilized survey data from 3500 elementary teachers who had participated in PD of varying duration to examine the relationship between PD and teaching practices. According to the self-reported data, the extent of participation in PD was strongly correlated with reform-aligned teaching practices. Similar results indicating improved teaching practices have been reported by other studies that further suggest a concurrent improvement in teachers' content knowledge (Bazler, 1991; Caton, Brewer, & Brown, 2000; Loucks-Horsley et al., 1998; Luft, 2001) and/or core conceptions and beliefs (Kazempour, 2009; Letter, Harwood, & Bonner, 2007). The theoretical model, developed by Fishman, Marx, Best, and Tai (2003), suggests an interrelated web of connections between PD and constructs such as teacher knowledge, beliefs and attitude, curriculum, teacher instructional practices, and student learning.

In addition to student outcomes and teachers' beliefs and classroom practices, Guskey (2000) also identifies teachers' reflections and learning as significant components of PD evaluation. The literature is replete with studies that utilize self-reported surveys, interview, and classroom observation data, primarily collected post PD experience, to explore teachers' knowledge, beliefs, and actions; however, we lack a clear understanding of teachers' learning experiences and reflections during PD opportunities (Hewson, 2007). In his review of the PD literature, Hewson utilizes the metaphor of "pathways" to describe the complex, systemic nature of teacher development in science, emphasizing the need to not only consider the outcomes of such programs, but also the course of development and the means by which these results are attained.

Previous research has focused on participants' instructional decisions as evident in their teaching practices upon returning to the classrooms. Such studies have indicated variations in the implementation of PD ideas in teacher's instructional practices and have reported on teacher perceived or actual obstacles such as lack of resources, time, and administrator support as well as the pressure of standardized testing and coverage of material that seem to prevent the actualization of some of teachers' ideas in the classrooms. In the case of PD participants who do not actually adopt PD ideas into their teaching or do so to a lesser degree, it is often difficult to determine whether this is due to external factors or if it may indeed reflect a lack of deeply rooted changes in beliefs. Hence, there is a need for immediate examination of participants' instructional decisions and their willingness and ability to apply PD ideas prior to their return to the classrooms and in the absence of the abovementioned obstacles and external factors. The current study aimed to extend our understanding of effective professional development by focusing on experiences of teachers during PD programs and their immediate implementation of newly gained ideas. We examined participants' written reflections and assignments during the course of a PD opportunity, to elucidate the process by which teachers learn about inquiry-based teaching, formulate beliefs about teaching and learning, and begin to incorporate these ideas in their instruction void of any apparent or existing external interference.

Methodology

This study employed a qualitative phenomenological approach to examine high school science teachers' experiences and cognitive representations of their evolving beliefs and ideas, as expressed in their written reflections and assignments, during a two-week inquiry-based PD opportunity at a large Midwestern university. The Summer Research Institute (SRI) was designed around a PD model, initially developed by Middendorf and Pace (2002) as a tool for enhancing college faculty's teaching practices (previously discussed in Letter et al. 2006, 2007). In brief, the model calls for teacher participants to identify a learning bottleneck- a difficult concept or process which students routinely have difficulty grasping- and work collaboratively with their peers to analyze and remedy the learning bottleneck through discussion and analysis. The PD examined in this study was organized around developing solutions to the student learning bottlenecks by providing teachers the opportunity to identify possible bottlenecks, individually and collaboratively analyze the problem and assess what is needed to grapple with the concept, and finally design an inquiry-based approach to teaching it.

The morning sessions, which will be the focus of this study, were devoted to pedagogy while in the afternoons, participants spent time in science faculty's research settings in an effort to gain experience and a better perspective on the process of scientific inquiry (Authors, in press). A team of science and science education faculty and graduate students facilitated the morning sessions. During the first week, there was an assortment of inquiry-based activities and discussions on a variety of topics including motivating students, scientific inquiry, misconceptions, assessment, as well as individual and group efforts aimed at developing a plan to resolve participants' identified learning bottlenecks. The activities and discussions immersed participants in the inquiry process, engaged them in critical thinking and problem solving opportunities, and promoted continual reflection on their beliefs and practices. The majority of the second week was spent on individual presentations of lesson ideas followed by discussion sessions focused on peer and facilitator feedback and questions about the proposed plans (Appendix A).

Participants

The participants included 21 public high school science teachers from across the state, including 5 male and 16 female teachers. Table 1 and Table 2, respectively, summarize participants' years of teaching experience and science subjects typically taught. Seven teachers possessed or were working toward a Masters' degre.

Table 1. Participants' Years of Teaching Experience

Years of Experience	Frequency
1	1
2-5	7
6-10	5
11-15	3
16-20	4
21-25	1

Table 2. Participants' Teaching Assignments

Science Subject Matter	Frequency
Biology/Life Sciences	1

Chemistry	2
Physics	2
Astronomy/Earth Science	1
Combination of 2 or more subjects	5

Data Collection & Analysis

To better understand participants' experiences during the PD experience, we focused on participant written words and reflections. We collected and analyzed several sources of participants' written artifacts including each participant's daily reflections about the morning sessions, daily written assignments focusing on questions related to the topics of discussion (Appendix B), and final written plans describing lesson or unit ideas they had developed to address students' difficulty with the bottleneck concepts.

Data analysis consisted of perusing through the written artifacts and identifying sentences and phrases referred to as "significant statements" (Moustakas, 1994) that capture participants' learning experiences and ideas. Next, we developed themes around the key ideas represented in participant statements. To ensure further triangulation, the two authors first individually analyzed each source of data, compiled significant statements, and developed themes. Afterwards, the authors held several joint sessions to discuss and refine the recurring participant statements and emerging themes.

Results

The findings will be presented in two sections. The first will focus on emerging themes about participants' ideas and reflections during the PD. The second will focus on the analysis of their final plans and emerging themes with regard to commonalities and distinctions in teachers' implementation of PD ideas in their plans. Analysis of the reflection data revealed recurrent statements within participants' written artifacts which were condensed into six key themes.

Theme 1: Enhanced Understanding of the Nature of Scientific Inquiry

On the third day, participants completed a series of activities and held several discussions on the topic of scientific inquiry. Participants' reflections, on this day and subsequent days, suggested a drastic modification in their understanding of the process of scientific inquiry as they began to develop a more accurate and encompassing concept of the process. For instance, almost all participants referenced their newly formed understanding of the process of science being more of a cyclical and intertwined series of activities rather than the linear model of the scientific method they had learned previously and continued to teach in their classrooms. One participant commented: "It was fascinating to discuss that our accepted scientific method does not in actuality follow what we all experience (both teachers and scientists). It's not an easy linear process as it seems." (Susan, Reflection 3) Another stated: "Dissecting the process of scientific inquiry REALLY helped me understand the thinking process of true science. Although I knew it, the dissection made the unconscious conscious" (Deb, Reflection 3).

Furthermore, participants suggested recognizing that in teaching science within the restrictions of the linear scientific method, they had inevitably limited their students' science experiences and deprived them of opportunities to engage in a more realistic process of scientific inquiry. About two thirds of the participants further alluded to having become more consciously aware that because of their "continued focus on isolated facts and content, the process through which that content and knowledge base has been derived is often ignored and also not made lucent for the students’’ (Amy, Reflection 3). June's third day reflection consisted of similar statements:

> I liked seeing how inquiry is not linear. So often we think in terms of the "Scientific Method” which is linear that we don't allow our students to "bounce around.” In our classroom we use what we know well and forget how we process when we don't know in science.

More than half the teachers reflected that traditionally they would "get really hung up on doing things right and getting the right results” and would now be "more open to errors and learning from mistakes.” (Lynn, Reflection 4) Bob and others reiterated Lynn's point about the significance of allowing students to experience scientific inquiry and begin to appreciate the importance of "making mistakes and not seeking to obtain a correct answer or results." They emphasized that teachers should refrain from "giving students the answers or pushing them to get correct answers all the time" since in reality "scientists are not 'given' the answers and not everything in science will have a right or wrong answer." (Deb, Day 4) Instead, they explained that teachers should focus on encouraging the students to communicate with each other as is practiced by scientists, and allow them opportunities "to make mistakes without penalty rather than be expected to carry out confirmation labs all the time." (Kirk, Day 5) This realization was attributed to their own experiences during the workshop as summarized by Danielle's comments:

> I realized today that when we all came up with different experiments and results it was okay. Actually I thought it was good because it showed all the different ways people can look at one question. It was like each group was standing at the bottom of the same pyramid looking at different sides. I feel this was a very important realization in that from now on when my students come up with different ways of looking at something I will start asking questions back to them instead of answering theirs! (Danielle, Day 4)

In general, participants embraced the non-traditional model of scientific inquiry they were introduced to in the workshop. They showed excitement and determination to modify their teaching practices to better reflect the more realistic model of the process of scientific inquiry in their classrooms. Several stated that this model not only "makes more sense" to them as teachers, but would probably be "a more comprehendible and approachable model for the students" (John, Day 3).

Theme 2: Evolving Ideas about Teaching and Learning

Examination of the participants' daily reflections and assignments indicated an emergence of ideas participants began to formulate about teaching and learning in general and in particular in the context of science.

Importance of motivation. One of the earliest and most recurrent concepts that participants alluded to was the importance

of motivating learners. Early on, one of the participants, Tina, reflected: "It is interesting to hear that the underlying feeling is how do we get our students interested and motivated?" Another participant, Susan, echoed these sentiments: "Someone said that students are just going through the motions of keeping busy until they are
grown up when they can do something IMPORTANT! We need to motivate students and show them they can do important things NOW!" Two ideas proposed concomitantly with the importance of motivation or as critical routes of motivating students included: 1) utilization of inquiry-based, instead of traditional, teacher-centered, instruction and 2) contextualization and relevancy of the concepts.

Inquiry-based teaching. As early as the first day, participants reported having developed a more accurate and informed image of the process of scientific inquiry and inquiry-based teaching, which they noted should be implemented in their classrooms. For instance, after a demonstration on the second day, in which they went through a series of questions and discussions regarding the dilemma of a baked loaf of bread that had failed to rise despite being baked in the same bread machine as another loaf that had successfully risen, participants noted gaining several ideas: 1) inquiry-based teaching does not necessarily have to include hands-on activities or involve numbers; 2) it can involve simple things, and 3) "interactive, cognitive processes are equally possible through questioning and looking for patterns" (Jocelyn, Reflection 2). As illustrated in the following statement by Jenny, participants also stated feeling increasingly more comfortable with adopting such an instructional approach and anticipated the implementation of this approach upon their return to the classroom.

> It was nice to learn you don't have to do all inquiry in the lab setting! I always thought inquiry had to be really complex and something I was not able to do or at least not in my classes. So far I have a good feeling about inquiry teaching in my classroom! I should be able to implement this in my 90minute classes! I am excited to learn more.

Relevancy of learning. The other idea developed closely with the two aforementioned ideas was the importance of contextualizing students' learning and making the concepts relevant to them. Reflecting on their own various experiences during the PD, participants discussed how they themselves were more interested in the learning when it was relevant and contextualized. For example, at the end of the first day, Bob expressed being "impressed with how interested I became with a seed's structure when described in the context of the bigger problem, bread making. I am quite sure that I will retain this knowledge better because it was associated with my existing experience." Participants further suggested that PD components, such as the bread demo, also allowed them to realize the significance of engaging the students in the learning. More than two third explicitly indicated an intention to use some form of a hook or engage activity to enhance students' interest. For instance, Kathy commented on another participant's inclusion of an engaging context in the unit plan presentation.

> Context is so important. How brilliant Jaime was to begin with chiggers. We were all quite engaged because of that. Kids love the "ewww" factor for anything. Why should they care? There are 30% of the kids who pay attention to anything and probably 20% who never care. Hitting the right hook is critically important for the middle group and maybe every now and then will get ones who will never admit they care. (Reflection 7)

Moreover, participants indicated recognizing that simply using a discrepant event or a hook, without contextualizing the learning or approaching it in a thematic manner and "bringing in the real world into our classrooms" (Jackie, Day 9), would be insufficient in maximizing students' interest and learning.

> Biology is relevant because most of what we discuss happens in THEM (students), but that isn't enough to make them care. Finding the "hook" is still a challenge. Some of the ecology suggestions actually can be used as themes in the cellular/chemistry/homeostasis standards. It will take some more investigation, imagination, and creativity on my part. (Katelyn, Reflection 3)

Consistent with their newly gained understanding of inquiry-based teaching, some participants, such as Heidi, suggested that developing thematic, inquiry-based units around students' own questions and areas of interest may help students in "the difficult task of making connections". Nearly two third of the participants discussed how thematic, contextualized teaching allows for more depth and breadth "under the umbrella of a theme or a context"

(Lucy, Reflection 3), rather than developing isolated lessons as many teachers admitted they had previously been doing.

Evaluating learning. In addition to gaining ideas regarding instructional approaches, participants also reflected on becoming familiarized with the appropriate assessment strategies in an inquiry-based classroom. The focus of the PD session on assessment was on a variety of formative assessment ideas; however, the discussions also included various forms of summative assessments as well as the importance of diagnostic assessment to evaluate students' prior knowledge and experiences. Participants reflected on gaining familiarity with a series of formative assessment techniques that they could utilize in their classrooms and emphasized the importance of utilizing these means of evaluation throughout the learning process rather than at the culmination of each topic or unit. Vicki, for example, discussed feeling "frustrated with student performance at the end of the unit. With use of these formative assessment techniques I will be able to detect and contend with the stumbling blocks that my students are tripping over right away rather than at the end." (Reflection 10)

Based on their reflections, almost half of the participants corroborated Vicki's comments and reflected on their reliance and overemphasis on summative exams and coverage of course topics, without rarely "checking where my students are" and using "homework problems to check their computational progress but not necessarily their theory progress." (John, Reflection 6) Teachers appeared to have also become cognizant of the significance of assessing students' prior understanding and experiences in order to more effectively facilitate their learning. Furthermore, they connected the discussion on diagnostic assessment to an earlier discussion on the topic of students' misconceptions and the need to enable the students to recognize their prior conceptions and possible contradictions that might exist between those conceptions and the scientific explanation.

> Students "invent" concepts from data/information and assimilate with their prior belief structure. Often this assimilation involves direct contradictions with their preconceptions. I have learned how important it is to understand their prior conceptions, allow them to reflect on those conceptions, and facilitate the assimilation process. (Bob, Reflection 3)

Theme 3: Initial and Evolving Ideas about Students and their Learning Difficulties

In the early stages of the PD, participants were asked to identify a learning bottleneck, a particular concept students typically seem to struggle with. The most commonly cited bottleneck concepts included projectile motion (physics), stoicheometry (chemistry), and photosynthesis/respiration, protein synthesis, evolution, biochemistry, and mitosis/meiosis (biology). The analysis of the initial PD days' assignments and reflections revealed factors that the participants initially contributed to students' difficulties with the bottleneck concepts. These
factors may be divided into three categories: student-related factors, content-related factors, and miscellaneous factors (Figure 1).

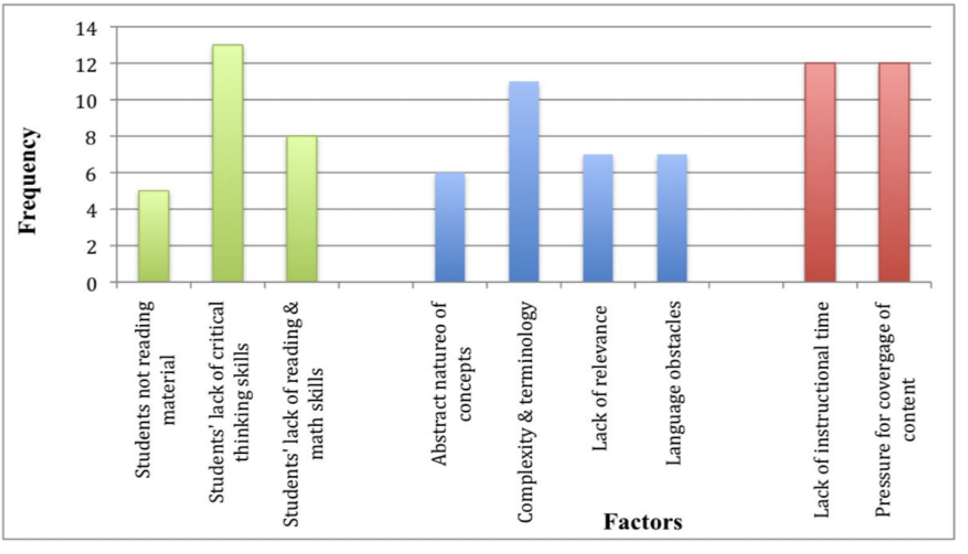

Figure 1. Initial Participant-Perceived Factors for Students' Learning Bottlenecks

A majority of teachers (n= 17) cited explanations that focused on the students. Several (n= 5) mentioned that the problem stems from students not reading the text or not doing so carefully. Some (n= 13) discussed students' lack of critical thinking and comprehension skills and their inability to focus conceptually because of their narrowed focus on the details. They stated that students oftentimes do not stop to think especially when they are dealing with concepts that involve complex multiple steps or patterns. Finally, a number of teachers (n=

8) mentioned their students' lack of reading and math skills or their inability to transfer their learning in those disciplines to science.

The participants focused equally on the bottleneck concepts, referring to the nature of these concepts as abstract, non-concrete ideas that made them especially difficult to visualize or comprehend by the students (n=6). Furthermore, some (n=l 1) alluded to the complexity of the concepts and the plethora of terminology often involved in the process of understanding them. Some of these concepts, as one biology teacher pointed out, "involve a complex set of systems within systems which are especially challenging to comprehend. My students need to understand chemistry to understand chemical reactions and equations in photosynthesis and respiration." (Katelyn, Assignment 1) Participants (n= 7) also discussed these concepts' lack of relevance (real or perceived) to students' lives, which lead to students' loss of interest or ability to learn the concepts. Finally, in addition to the abundance of terminology, one third of the participants also referred to the obstacle of language that exists with some terms, such as adaptation or theory, that are used differently in science than in everyday language, creating further confusion and difficulty.

Other than the reasons cited in the previous two categories, more than one half of the participants (n= 12) also mentioned lack of time and consistent pressures to cover material and
prepare students for tests, as other possible factors in students' difficulty with appropriately understanding the material in depth. Absent from the factors cited by the participants as instrumental in students' difficulty with the bottleneck concepts were those related to the teachers and their instructional and possibly management approaches. The overwhelming focus of the participants, in explaining the bottlenecks, was on the students and the concepts.

As they progressed through the PD experience, their reflections and assignments revealed a shift in participants' perspectives as they began to focus more on themselves and their teaching rather than the factors mentioned above. Teachers reflected on the importance of providing students with opportunities to develop critical thinking, problem solving, and analytical skills as well as encouraging them to pose scientific questions.

> Today I realized the importance of using activities and ideas that will evoke meaningful thought processes. We discussed how to develop the skills to interpret the information they will receive in life and the importance of analysis. Students need to be taught how to use good

> critical thinking skills to make good valuable decisions. (June, Reflection 5)

Admitting that students are often accustomed to viewing concepts non-critically and seeking "correct answers", the participants emphasized the importance of enhancing students' learning experiences. One participant's reflection, on the significance of getting the students to break away from giving up easily and looking for the correct answers, particularly stood out.

> To ask questions is the central hub upon which the wheel of science turns. I aspire to model to my students that to a scientist, the phrase "I don't know" is the beginning of a journey, not an end, as they so often presume. (Vanessa, Reflection 10)

Teachers' recognition of the value of thinking out loud, modeling the thinking processes^ and promoting such processes in the students was evident in various reflection entries.

> It was good to dissect how we think, because this really needs to be modeled for our students. It is disconcerting and frustrating to think that our students haven't had a sense of wondering and questioning about the world around them before we get them. So we need to constantly model that for them and put them in situations where they have to think and question. (Katelyn, Reflection 3)

A fourth of the participants also remarked about the difficulty of "breaking down the thought processes and looking at ideas from a student's point of view to attempt to figure out what they do not understand." (Susan, Reflection 2)

Finally, the participants commented on how a contextualized, inquiry-based instructional approach in which students are encouraged to think critically initially requires an emphasis on the conceptual understanding of the processes and ideas before the relevant terminology is introduced. Participants reflected on their own individual responsibility as teachers in developing creative inquiry-based learning experiences and facilitating students' learning even if students seem apathetic to their learning. Vanessa's final reflection embodies other participants' sentiments regarding the significance of the development of critical thinking in students.

> Creating a more student centered environment that allows for investigations, discussions, analysis, and so forth produces a climate where students become more accountable for their own learning. Students perform at a higher cognitive level when they are engaged, when they are self-motivated and when they become responsible for their own learning. Universities want students who can think, not simply memorize. Students need to know now more than ever how to research, how to distinguish between reliable and unreliable sources, how to discriminate between science and pseudoscience, how to analyze, and most fundamentally how to think. And this is true in real life too. So the teacher must act as a facilitator and a as a resource for students, not merely as a disseminator of rote facts.

Theme 4: Significance of Self-Reflection

Beginning midway in the PD, participants began remarking on the impact of the daily written reflections and opportunities for reflecting on their views and teaching practices both individually and in groups during the morning sessions. Their comments indicated an awareness of the importance of such reflective actions in making explicit some of their beliefs about the students, the learning process, teaching, and the nature and process of science inquiry, as well as, enhancing their awareness and scrutiny of own instructional practices. As one participant put it, the reflections served as "an approach that placed each participant in a position to reflect on his/her teaching method and articulate it in a comprehendible manner for the other participants. It's an eye opener in itself." (Max, Reflection 1)

As a consequence of reflecting on their teaching practices, participants identified several elements that were absent in their teaching such as the use of engaging hooks, student-centered inquiry-based learning, student questioning, and use of outdoor resources, as have been alluded to in the above sections. Bob's comment (day 2), "How can students ask questions when I am always talking?" echoed the concerns of a number of teachers who had become conscious of their dominant role in the classroom and the lack of student involvement and action in the learning process. Dan and others reflected on the "need to really do some thinking with regard to how to give meaning to the topics... to create some situations where students are engaged in real science." (Reflection

4) Majority of the participants remarked on their newly gained sense of appreciation for what their students feel and experience in the classroom. A number of teachers extended this to reflecting about the current state of science education and possible restructuring of school science. For instance, upon hearing the biology related lesson ideas during the participant presentations of their plans, Susan, a physics teacher indicated: "I am thankful I do not have to wrestle with the complexities of biological processes. I am now recognizing why the argument for moving biology to more upper level course has so much validity." (Reflection 8)

There were also statements regarding a newly gained sense of excitement and passion about science and science teaching. Almost all participants expressed enthusiasm and eagerness about employing their newly gained understanding and skills in their classrooms and transitioning to inquiry-based teaching. A number of participants discussed a newly gained interest in "tapping into outdoor resources and learning opportunities and breaking away from the confines of the classroom walls and textbook driven activities in order to generate awareness, open discussion, writing and reflection." (Bonnie, Reflection 5) and using "fossils and other objects to study science indirectly." (Jack, Reflection 4) Additionally, some participants reflected on their previously limited focus on individual standards and isolated textbook chapters in contrast to their current intentions to emphasize a thematic and contextualized instructional approach.

> Today's outside ecology "lesson" is something our kids would love and made me realize that I am so focused on classifying lessons by units that ecology gets left to the end. Why not incorporate ecology throughout the year through the questions students ask after their outdoor observations? It was frustrating today not to be able to ask more questions. My mind wasn't open enough, as will be the case with the students. Much practice will be needed. (Katelyn, Reflection 5)

Theme 5: Contemplating Possible Challenges on the Path

The analysis of the reflection data also revealed a small number of initial concerns and confusions as well as challenges participants envisioned facing upon their return to the classrooms. Early on, two of the participants expressed understanding "why teaching should be inquiry-based," but "not feeling quite comfortable with the approach." (Laura, Reflection 2) Neither of these participants raised this issue in subsequent reflection entries and one later reflected, "the more I see it work the better my comfort level will be'' (John, Day 4). There were several other comments regarding the need for further practice and greater attention to the details involved in implementing inquiry-based teaching in the classroom setting. For instance, Katelyn expressed possible difficulty with deciding on the amount of guidance to provide students in the process.

> It was interesting to do this activity with someone who was fairly clueless about what to do today even though we were all science teachers but teaching different fields of science. Similarly, students often just stare when given open-ended activities. Judging how much information to give or withhold will be the challenge. (Reflection 4)

Almost every reflection entry focused on the individual's own teaching and the need for making changes to pre-existing lessons and instructional practices. Several participants initially expressed feeling "a bit overwhelmed" at the thought of "needing to overhaul my teaching and curriculum,'' but gaining a greater sense of comfort "seeing the various workshop activities and hearing comments and discussion points about taking it in strides and making changes here and there as I move forward" (Vickie, Day 9). As the PD progressed, a number of individuals expressed similar comments as Vickie and acknowledged that the transformation must be a gradual process, with "small modifications along the way" (Susan, Day 7), and that it may not be necessary or even feasible "to revamp their entire teaching and curriculum in one semester or year." (Jayne, Reflection 6) This knowledge brought a sense of relief to participants, in particular those who had earlier conveyed concern about their ability to undertake such a seemingly colossal task. Dealing with students' questions, the level of guidance to provide them throughout the learning process, and countering students' preoccupation with being "right" were also possible concerns and challenges that were discussed by several participants midway in the PD.

> This makes me think of my students who have been in the public school system. They want the right questions and the right answer. I like to adopt this activity in my class, but there are logistics to work out. What do I do with the kids who want to get the "right questions" or

> want the "right" answer and assume that anything beyond that is equally wrong? What to do with the ones who will goof off? Of course I hope that inquiry will expand their thinking but how do we prevent "relapse"? (Vanessa, Reflection 5)

Finally, a small number of participants, including June, reflected on feeling restricted by "the schools' overemphasis on test preparation and coverage of content while our voices as teachers go unheard." They discussed understanding "the power of contextualized teaching and the relevance of some topics more than others" and their desire to implement these ideas, but "feeling constrained by time, standards and testing. So even if we see and understand what's happening in our classrooms may not be 'the best' approaches, we as teachers don't get to make the rules, which is unfortunate." (Reflection 8) Interestingly, even this small group of teachers which alluded to possible difficulties and challenges within the structure of the educational system, expressed willingness and interest in "applying what I have learned here to be effective.'' (Laura, Reflection 6)

Theme 6: Effective Features of Professional Development

Participants frequently reflected about the impact of the PD, commenting on their "immense growth and new outlook on how I approach teaching and assessment" (Bonnie, Reflection 8) and the impact of the PD in "changing our mindset and becoming open to modifying our perspectives on teaching." (Katelyn, Reflection 9) Another participant, Kirk, identified the SRI as "the most valuable PD workshop I have ever attended. Too often PD programs are lost in a whirlwind of information being presented. The SRI provided opportunity for professional growth through collaboration, lesson development, peer feedback and immersive activities." The data revealed a number of PD features that were cited as significant in participants' learning and growth.

Teachers as active empowered participants. A number of teachers discussed feeling "empowered", "appreciated", and "respected" as workshop participants. For instance, several participants such as Bonnie, expressed gratitude for workshop facilitators' "respecting our opinions and treating us as professionals each of whom possessed a level of expertise to contribute." This was mainly in reference to the various small and large group discussions during which teachers discussed, among other topics, their classroom teaching experiences, issues faced within the classroom, and their PD experiences. However, feeling empowered and valued also extended to their involvement in all aspects of the PD as active participants rather than "being presented information and instructed on what to do in a typical lecture format.” (Susan, Reflection 10) They reported that the firsthand experience with learning through inquiry allowed them to: 1) have a "better understanding everything involved, from the thinking process to the constraints, and be able to facilitate this type of learning in my classroom” (Katelyn, Day 9), 2) have a better sense of how their students might experience and think about the same phenomena, and 3) become more convinced as to "why I should do this and how it will help the students because I became curious and interested in what we were doing and feel students would too!” (lune, Reflection 1)

Another closely related aspect of the workshop that participants found valuable was the facilitators' modeling of effective inquiry-based instruction during the chosen activities and discussions as well as the emphasis on science process skills while de-emphasizing lecture and teacher-centered instruction. Kirk's reflection (Day 8) below, echoes repeated references by participants about the value of the modeling of inquiry-based instruction and the discussions that ensued focusing on the various aspects of inquiry-based pedagogy.

> Rather than telling us what inquiry-based teaching is, as is often done in our staff development workshop sessions, the facilitators modeled that for us. We got to see how they engaged us in a topic, involved us in inquiring and asking questions, interacted with us during the process, and prompted us to communicate and collaborate with one another. It was very helpful for me to see this on a daily basis so that I can see this in practice and hopefully be able to do the same in my own classroom.

A plethora of activities such as the bread demo, enzyme activity, and outdoor question forming activity provided the participants with opportunities to witness and experience 1) an emphasis on process skills such as questioning, making observations and inferences, and collecting and analyzing data as well as 2) features of inquiry-based instruction such as engaging students, posing questions, ongoing assessment of student learning, application of classroom learning to students' lives, and student-driven, teacher-facilitated discussions.

The discussions that followed allowed participants to "reflect on my teaching and see what others do and realize that I may not be alone in my struggles’’ (Lucy, Reflection 5), gauge the efficacy of their instructional practices, and begin to consider "changes I need to implement once I return to my class” (Deb, Reflection 6).

Community of teachers. Participants noted the effectiveness and value of the discussions and collaborative efforts that occurred both at the small team and whole group levels. This was especially applicable in their work on bottleneck concepts and drafting plans for developing lesson and unit ideas. During the early phases of analyzing their bottlenecks, participants were able to assist each other in recognizing the possible areas that students may have difficulty grasping or obstacles that typically interfere with students' understanding of the concepts. Many participants reflected on the value of discussing their bottlenecks with people outside of their field who would be in a similar situation as the students. They commented on their own inability to step outside of the "expert” box and think from their students' perspective. However, through talking with a peer and discussing their usual instructional approach, they were able to receive constructive feedback or questions that allowed them to recognize the details they were overlooking or assuming in their instruction. For instance, Bob explained how the group discussion had assisted him in realizing "how our ‘expert' understanding was not equivalent to what our students' understanding is.” He was able to understand that "my students' bottleneck resulted in evaluating the result of forces in Newton's 3rd law as opposed to evaluating the forces themselves,” while Jocelyn who was in Bob's team reported how he had helped her recognize that "vocabulary can be part of the road block between students and their understanding” of biological concepts such as protein synthesis.

The same was true in their discussions with the main workshop facilitator, Dr. B, whom they mentioned could easily relate to their experiences because of his "experience teaching nonmajors” and prompted them think out loud about their thinking (Katelyn, Reflection 5). During the presentation of their plans, teachers further received extensive feedback from their peers and the facilitator. These sessions were equally valuable for the participants by allowing them to critique one another in a constructive manner in order to support and assist each other in improving their lessons. Overall, the discussions about the bottlenecks allowed participants to "reflect on own teaching” and recognize the minuscule, yet significant, details that may have been overlooked or not addressed adequately in their classrooms. The consensus view among the participants was that the bottleneck discussions were "an eye opener" and allowed them "to see things from a whole different angle." (Katelyn, Day 5)

Finally, participants continuously referred to a sense of collegiality and community that had been developed throughout the PD. As early as the first session, participants reflected on feeling a sense of "comfort" and "support", as opposed to feeling "alone" and "isolated." They realized that other teachers are facing common issues such as difficulty motivating students, feeling restricted or pressured by state tests and standards, and getting students to understand some of the main concepts, which they began to identify as bottlenecks. They also found the peer connection valuable because they could learn from one another's successes and struggles (Lynn, Reflection 1). The discussions about their bottlenecks and other workshop topics, both at the small and large group levels, allowed participants to exchange and generate ideas to take back to their classrooms. Participants, such as Sam, indicated an appreciation for "the diversity of the group and the insights everyone shared." Participants were able to provide each other with support, encouragement, and consistent motivation in overcoming their bottlenecks as well as other instructional issues they were facing. They were appreciative of the support and encouragement they received from their peers and indicated an interest in preserving this support system during the academic year for encouragement and developing further ideas (Tina, Reflection 9). Many anticipated "meeting again" during the academic year follow-up workshops to discuss "how we are each implementing these ideas in our classrooms." (Susan, Day 10)

Implementation of PD Ideas into Teaching Plans

The second week was devoted to participants' presentations of their plans to overcome students' learning bottlenecks. The final drafts of their plans, with the exception of four that were either not submitted or extremely brief to analyze in detail, were analyzed in order to ascertain possible patterns in terms of instructional approaches evident in their plans. Table 3 highlights the four categories (profiles A-D) that emerged in terms of teachers' immediate implementation of PD ideas in their plans.

On one end of the spectrum, there were two teachers (profile A) who indicated including more activities and discussions in their plans, but they were still initiating their lessons with the coverage of terminology and background information. It appeared that they were using the activities and the discussions to merely assist students conceptualize the meaning of the terms. An example of this was Jocelyn who wanted to help her students understand dihybrid Punnett squares and making probability predictions for various types of crosses. The summarized description of her plan in Table 3 indicates that she was interested in engaging the students and introducing more "hands-on" activities, but she continued to focus on providing students with the terminology and background information before they had a chance to actively explore the concept on their own along with teacher-directed discussions.

The next category of participants included five teachers (profile B) who focused on a process, such as protein synthesis, and simply tweaked their approach without contextualizing the learning or allowing more student inquiry. An example of this was the idea of simulating protein synthesis by having students act out the process in a play written by the teacher. These participants did not discuss any type of engaging activity or ways to pique students' interest in the concept and simply used the play to allow students to visualize the process, which may be abstract to many.

Profile C, the largest category, consisting of eleven participants, provided a good context for their lessons, but chose a more guided inquiry approach. For instance, Katelyn began her protein synthesis lesson with a video clip discussing the impact of incorrect protein synthesis resulting in the Tay-Sachs disorder. She suggested asking students a series of questions about the video and as review of what they have learned about DNA before prompting this question: "How can DNA direct production of proteins?" Students would work in teams to "create a code that could translate a message using 4 symbols into one using 20 symbols and creating a message and testing it with other teams." This would be followed with a small discussion and another student activity utilizing puzzle pieces to simulate the process of "going from the DNA code to chains of amino acids" which they would then present to their peers. In this example, we notice an appropriate use of a "hook" to engage the students followed with a series of questions and discussions, interspersed with activities, during which students model the process using manipulative s.

Finally, there were three teachers (profile D) whose lessons or units utilized strong hooks to engage students in the learning and included more open and student driven inquiries. An example of such a plan was Bonnie's lesson idea about photosynthesis and cellular respiration. She began her lesson with a problem, which served as a hook and then allowed the students the opportunity to design experiments and discuss with their peers in an effort to better understand these two interconnected processes. Another example of a more open-ended inquiry was Bob's plan in providing the students with an opportunity to have a better understanding of Newton's third law. He also began his lesson with a challenge to the students which was followed by several rounds of student designed investigations and class discussions to generate conclusions regarding interaction forces. Excerpts from both examples can be found in Table 3.

Table 3. Teacher Profiles Based on Differences Evident in Participants' Bottleneck Plans

Profile	Frequency	Instructional Approaches Evident in the Bottleneck Plans
A	2	Include more activities and discussions but initiate lessons with coverage of terminology and background information Excerpt from Joyce's plan: Students will first discuss and identify their own traits. The question of inquiry will be asked: "why is this so?" After this, there will be discussion about inheritance. This would be a good time to introduce the terms they will need to know. This time I will help them remember terms by using a "picture association" technique. What I will do differently, will be to introduce some manipulatives that students will be able to physically move around and pair up.
B	5	Focus on a process (ex: protein synthesis) with simple tweaking of approach without contextualizing the learning or allowing more student inquiry
C	11	Provide a good context for lessons but a guided inquiry approach during student explorations
D	3	Utilize strong hooks to engage students in the learning and include open and student driven inquiries. An excerpt from Bonnie's plan: The students will model the relationship when they design an experiment to better understand what is occurring within each system: a fish bowl with water and Bromothymol blue, a fish bowl with water and goldfish, a fish bowl with water and Elodea, and a fish bowl with water, goldfish, and elodea. By allowing them the freedom to design their own experiment I am providing them with the opportunity to explore all of their ideas on how to keep the fish alive which will help them to connect to the two processes. An excerpt from Bob's plan: You have recently been hired by Alcoa which is marketing an aluminum alloy as a lightweight substitute for steel in the bodies of several models of cars and trucks. One of the marketing claims will be that this alloy is more resistant to permanent deformation than steel. The metal deformation division has engineered two heavy-duty strain-gauge force sensors that can be attached to vehicles to measure the force that each receives from the other in both elastic collisions and steady-force situations. You need to know how these forces will compare in all experiments involving the new alloy.

Although there were variations in Profile A-D's approaches, common features were also particularly evident across profiles. One feature incorporated especially in profiles C and D's plans, was the use of some form of a "hook" or engaging activity or scenario to enhance students' interest and draw their attention to the lesson or unit concepts. These hooks included showing video clips, using demonstrations or discrepant events, and posing problems or scenarios to pique students' interests and focus their learning. For instance, Susan introduced her lesson with a video clip from the movie Road Trip and posed this question "Can you launch your parents' vehicle over a river bed like the example we watched in the movie?" She used the clip to excite the students and challenge them with the above problem that would guide the remainder of their learning experience. As another example, Katelyn began her lesson on protein synthesis with a video clip from the PBS "Cracking the Code" program, which focused on possible adverse impacts of errors in the process of protein synthesis as with the case of Tay Sachs. Bonnie initiated her lesson on photosynthesis and respiration by challenging students to address the problem of keeping fish alive in a fish tank at a miniature golf course "to get them to begin thinking about the relationship between plants and animals and serve as an introduction to these two concepts." (Assignment 8)

Throughout their lessons, participants focused on providing students the opportunity to collect and analyze evidence. Most (with the exception of profile A participants) suggested use of journals by students as a continuous evidence collection tool as well as a means to analyze their observations and reflect on the process. A number of participants also referred to incorporating components in their lessons that would encourage students to apply their reasoning and critical thinking skills to explore patterns within their data. Another common feature was the inclusion of non-traditional means of instruction or assessment including the use of plays, songs, and poems. For example, two of the teachers who focused on protein synthesis as their bottleneck utilized plays performed by students to demonstrate the various components of the process.

Finally, almost all of the submitted plans, across the four profiles, included a directed focus on questioning and discussions as tools for facilitating and assessing student learning. In some of the plans, the discussions were more teacher-centered while in others the discussions focused on students' explorations and findings and teacher facilitated connection of student ideas to scientific concepts. Regardless of the type of lessons, teachers included numerous questions or made reference to asking questions during the learning process.

Discussion and Implications

Previous studies focusing on PD in science education have highlighted the impact of PD on teachers' beliefs, knowledge, and teaching practices (e.g. Kazempour, 2009; Letter et al, 2006) which have been suggested to be associated with students' understanding and attitude (Fishman, et al, 2003; Supovitz & Turner, 2000). However, these studies have focused on pre-post or often post PD only analysis of participants' beliefs, understanding, and practices through the use of surveys and interviews. A number of studies have reported effective features of PD as identified by participants through self-reported surveys conducted post PD (Banilower et al, 2007) or the meta-analysis of PD studies (Blank & de la Alas, 2009). This study aimed to extend our understanding of effective professional development by focusing on teachers' experiences, the development of their beliefs and understanding, and their perspective on effective components of the PD, as communicated by them through their written reflections and assignments, during the PD process.

PD Experience and Teacher Development

Building on previous research, our findings further revealed a web of interrelationships within and between (1) participant-identified beneficial programmatic features and participants' experiences, (2) processes of personal, social, and professional development (Bell & Gilbert, 1996), and (3) evolving conceptions and beliefs (Figure 2).

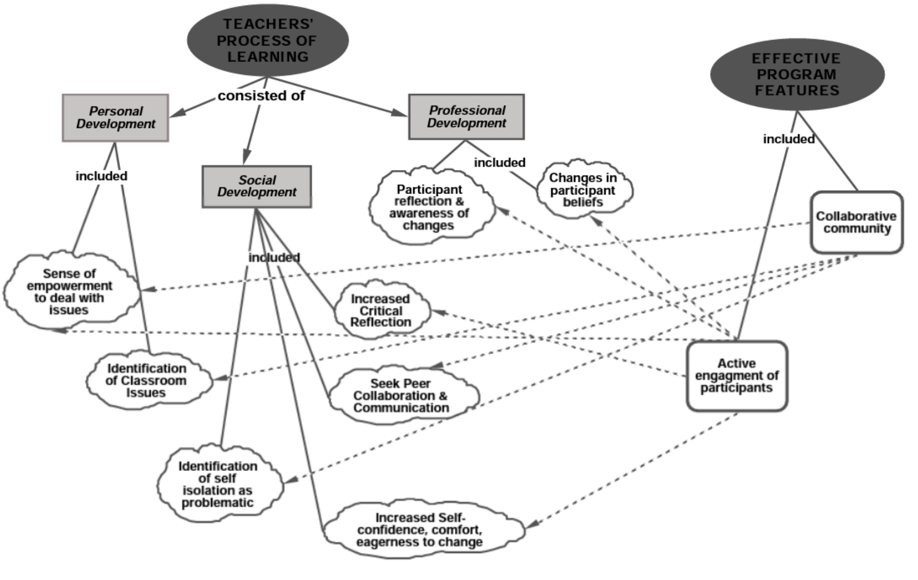

Figure 2. Web of interrelationships between programmatic features, participants' experiences, and the processes of personal, social, and professional development.

Personal development refers to teachers' recognition and identification of possible problematic areas in their practice and gaining an increased sense of empowerment to deal with the problems during the process of teacher development (Bell & Gilbert, 1996). Early on, participants experienced personal development when they identified students' learning bottlenecks and possible reasons for students' lack of conceptual understanding. As they progressed through the PD, they shifted to identifying themselves and their teaching practices as influential factors impacting student learning. They reflected on the inefficiencies of their classroom instructional approaches which they viewed as highly structured, teacher-directed, and void of elements, such as the use of engaging hooks or encouraging student questions, that they had come to view as crucial factors for successful science learning.

Additionally, Bell and Gilbert's model (1996) suggests that teachers experience professional development as they assume the role of learners (Darling-Hammond & McLaughlin, 1995), fully cognizant of the unfolding changes and development in their increasingly articulated and reflective beliefs about science instruction, and find it necessary to implement the newly gained ideas in their teaching (Hewson, 2007). Participants discussed the importance of motivating students by engaging them in inquiry-based, student-centered, contextualized and relevant learning opportunities. They were able to gain a more accurate and informed understanding of inquiry-based learning and indicated a sense of comfort and enthusiasm in implementing such pedagogical approach in their classrooms. A number of the participants discussed a shift, from a simple focus on coverage of isolated standards and topics through disconnected lessons, to creating thematic and contextualized units that would encompass a more meaningful and interconnected web of concepts.

Another example of how the teachers underwent personal and pro fessional development during the PD was the major dissonance they experienced (Thompson & Zeuli, 1999) upon recognizing that the linear scientific method that they had learned and continued to teach is a simplistic and inaccurate depiction of the process of science. They understood the urgency to amend their invalid classroom portrayal of science and narrow focus on factual information. Teachers discussed their intentions to reflect a more realistic picture of scientific inquiry in their classrooms by allowing students opportunities to experience the process firsthand and be able to make errors, arrive at different solutions, and learn to share and communicate ideas. Similarly, participants proposed to deal with students' difficulty in thinking through some of the abstract concepts by providing them with ample opportunities for inquiry-based learning that would allow students to develop critical thinking, problem solving, and analytical skills. They planned to encourage students to pose questions and focus on understanding scientific practices as opposed to memorizing isolated facts and terminology.

The analysis of participant reflections suggested that they judged several factors as influential and effective in their professional development. One category of factors dealt with the participants' perceptions about being treated as valued, experienced professionals and their sense of empowerment as a result of being situated in the learning experience as active participants. These results have been echoed in previous studies including Putnam & Borko's (1997) review of PD studies, which identified the abovementioned features as important factors. The facilitators' method of modeling various components of inquiry-based learning through the demos and hands and minds-on activities was cited as another vital factor which allowed participants to witness firsthand the emphasis on process skills rather than terminology and key features of inquirybased instruction such as engaging students and sparking their interest. Previous PD studies (e.g. Darling-Hammond & McLaughlin, 1995) have emphasized the imperative nature of allowing participants to witness and experience inquiry-based learning and teaching.

Another aspect of the workshop cited as a significant factor in participants' learning and development was the opportunities for collaborative activities and discussions with their peers and the facilitators, which were central in their Social development. Social development is initiated with the teachers' recognition of, and deeming problematic, their "isolation from their peers", followed with their attempts to find the means to share and discuss experiences and problems with a community of peers whom "offer critique in nonjudgmental fashion" (Hewson, 2007, p. 1184). Consequently, peer collaboration offers teachers opportunities for critical reflection on their own teaching practices and "renegotiating and reconstructing their shared knowledge about what it means to be a teacher of science" (Bell & Gilbert, 1996, p.26). The other positive outcome of the process of social development is an increase in teachers' sense of self-confidence (Hewson, 2007).

The group activities allowed them firsthand experience with the process of inquiry, opportunities for collaboration and communication, and an improved understanding of their students' experiences and possible barriers they may face in understanding science concepts. The collaboration was especially fruitful and effective in their identification and attempts to resolve their students' learning bottlenecks. The bottleneck related activities and discussions allowed the participants to share ideas, think out loud about their approaches and thought processes, and step outside the "expert' box they had been accustomed to and view the ideas from the students' perspective. This opportunity allowed them to not only critically reflect on their approach and identify the intricate elements they were assuming or ignoring to address, but also receive multiple rounds of feedback from their peers and facilitators. Not surprisingly, the sense of collegiality and community that developed among the participants was reported as significant in allowing them to feel a sense of support and comfort as opposed to isolation and desperation. Aside from the issues of dealing with their bottlenecks, their newly formed community offered critical support and comfort through discussions, which highlighted their common classroom issues and struggles, and allowed for exchange of ideas.

Overall, participants valued the practicality of the workshops and were especially appreciative of the time and effort spent on connecting the workshop ideas to an issue from their own classrooms. This allowed for the workshop content to be relevant and contextualized, providing an opportunity for the modification of their perceptions and instructional practices. Participants should have opportunities for immediate implementation of the workshop objectives and connecting them to classroom practices. The immediate application allows for prompt feedback from peers and especially facilitators who can assist by redirecting or highlighting any lingering misconceptions.

Previous studies focusing on participants' post PD classroom practices have shown variations in teachers' approaches to implementing the PD ideas in their teaching (e.g. Kazempour, 2009; Letter et al., 2006). These studies have suggested that the differences in instructional practices may be related to external factors including pressure to cover content, lack of administrative support, and lack of time. The current study's participants were implicitly invited to implement the workshop ideas as they developed their plans during the second week of the sessions. This allowed for an examination of the extent and scope of teachers' application of PD ideas and skills in their instructional decisions in the absence of perceived or genuine external factors and obstacles. This allows for a clearer understanding of the extent of changes in participants' beliefs beyond what is articulated in their writing or reflected in possible survey findings.

The analysis of data revealed common features as well as differences among teachers' immediate implementation of ideas in their instructional planning. Workshop ideas common among teacher plans included the use of engaging activities, focus on collection and analysis of evidence, greater involvement of students in the process of learning, and a major focus on student-student and student-teacher interactions through questioning and discussion. The majority of the participants contextualized their lessons and implemented an either guided or open-ended inquiry approach in order to allow for greater student participation and autonomy, relevancy and in-depth learning, and increased opportunities for problem solving as well as critical and analytical thinking.

The findings related to profile B teachers may have several explanations. First, it may be that for the purpose of writing out their plans, these teachers may have simply focused on how they would attempt to allow students to visualize and better understand the particular process, and excluded the explorations and activities they would otherwise provide for students to develop an in-depth and contextualized understanding of the concept. Conversely, it may be that these teachers simply view inquiry-based learning as allowing for greater student involvement and modeling, which are essential but not exclusive components of inquiry. These participants' reflection comments, which indicated their intentions in allowing for thematic contextualized learning, opportunities for collection and analysis of evidence, ample discussion and collaboration among students, and ongoing assessment of student learning, point more favorably to the first proposed explanation.

Futhermore, although it is reassuring that profile A teachers did gain an appreciation for the importance of classroom discussion and greater student participation, this is overshadowed by their continuing focus on terminology, facts, and coverage of information that leads them to continue with a seemingly content-focused, teacher directed pedagogy. Again, several explanations may exist, including these participants' potential beliefs about classroom constraints such as time, pressure to cover content and prepare students for exams, or issues with classroom management that have inhibited them from taking a more drastic approach to resolving their students' learning bottleneck.

The variations founds in the plans, as well as the challenges some of the teachers discussed in their reflections, highlight a critical need for PD workshops to provide a fuller picture of inquiry-based approach to teaching. The demos and activities represented powerful snippets of effective teaching; however, to further develop and enhance teachers' understanding and implementation of inquiry-based instruction, it may be necessary to include more lengthy simulations and firsthand experiences that more realistically illustrate the interconnected components, as they would be carried out in an actual classroom. For example, instead of, or in addition to, conducting several demos, short activities, or discussions that allow participants to understand the ideas of assessing prior understanding, effective questioning, inquiry-based learning, and contextualization of concepts, it may prove more effective if PD facilitators model an abbreviated version of a complete inquiry-based learning scenario that allows the participants to personally experience and witness the entire process as students would in an actual classroom. Otherwise, participants may continue to leave PD workshops having gained numerous ideas and a better understanding of inquiry-based learning, but unable to implement them successfully and attempt to simply tweak their traditional lessons with a few of their newly gained ideas.

Implications for Research

There continues to be a need for further understanding and implementing effective PD. The literature on PD points to several key ideas that were also supported by the findings of this study, but unanswered questions remain abound. Further studies are necessary to explore teachers' experiences and beliefs while they are participating in the workshops rather than doing a pre-post or post-only investigation. Chronicling participants' views and ideas as they develop throughout the workshop will allow educators to gain a better sense of how participants perceive and internalize workshop activities and objectives. Future research should also examine how teachers' thoughts and experiences, upon return to the classrooms, correlate to their thoughts and experiences during the workshop. This requires documenting participant reflections throughout the process which would allow for a depth and breadth of data that could potentially reveal, among other things, teachers' ideas of inquiry-based teaching and learning, difficulties teachers face in the implementation of PD ideas, actual and teacher-perceived external constraints, students' feedback and experiences with the inquiry-based instructional approaches.

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Appendix A. Overview of Key PD Activities During the Morning Sessions

Day	Sample Activities
1	Inquiry Activity: Bread Problem
	Focus on asking questions, thinking about prior conceptions, collecting and analyzing evidence
	Initial discussion about bottleneck concepts
2	Inquiry Activity: Guest speaker brought evidence used in art history
	Discussions focused on the use of "evidence" in various fields and the various interpretations that can be arrived at using the same evidence (science, art, etc)
	Continued conversations in small teams about bottleneck concepts
3	Inquiry Activity: Fossils from Allen's creek
	Focus on thinking out loud, modeling "expert" thinking, analyzing data/evidence
	Continued conversations in small teams about bottleneck concepts
4	Inquiry: Enzyme activity
	Focus on engaging students' interest, using a "hook" or discrepant events, and that there are not always right answers in science
	Group activity: Prepare a "bad lesson", present it, and discuss what should we avoid doing now that we have seen the bad lessons?
	Continued conversations in small teams about bottleneck concepts
5	Inquiry: Squirrel monkeys
	Focus on analyzing data, interpreting what the data mean, discussing the importance of acknowledging possibility of multiple interpretations within science, understanding students' thinking
	Continued conversations in small teams about bottleneck concepts
	Begin bottleneck plan presentations
6	Discuss each plan in small groups and as large class to provide feedback to presenter
	Activity: formative assessment tools
7	Continue bottleneck plan presentations
	Discuss each plan in small groups and as large class to provide feedback to Presenter
8	Continue bottleneck plan presentations
	Discuss each plan in small groups and as large class to provide feedback to presenter
	Discussion on "collaborative learning"
9	Continue bottleneck plan presentations
	Discuss each plan in small groups and as large class to provide feedback to Presenter
10	Group Activity: discuss and write list of recommendations for each of these questions:
	1. What would make inquiry teaching the most effective?
	2. What to do when designing an inquiry-based unit aimed at addressing a particular learning situation/
	Groups exchange lists, discuss, refine lists
	Whole group creation of a Manifesto: whole group recommendations

Appendix B. Sample Daily Assignment Questions/Instructions/Prompts

Day 1:

1. Identify a specific moment in your course in which your students face a learning bottleneck (i.e. something that is essential for their success, but which, semester after semester, large numbers of students fail to grasp).
2. Describe as precisely as possible what they are getting wrong (what is the nature of the bottleneck?)

Day 2:

Readings:

Inquiry in the National Science Education Standards p 13-38

How Experts differ from novices. In How People Learn (2000). P. 31-50

Assignment:

1. Briefly reconsider the bottleneck you have chosen. (Is it too big? Too vague? Is it essential to your students' success in your course?) Describe the bottleneck again, as clearly as possible. Is this connected with any common misconception in your field?
2. Define what an expert in the field would do when presented with the challenge of this bottleneck. What are the steps that an expert goes through to complete this task? (by thinking of what an expert does, we can begin to see where our students may be skipping important parts of the process.)