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Impact of Inquiry-Based Professional Development on Core Conceptions and Teaching Practices: A Case Study

This case study focused on changes in teachers' core conceptions and the translation of such changes to classroom practices needed to enhance students' science learning experiences.

Introduction

Teaching science through inquiry-based, student-centered instructional methods has been consistently emphasized by science education reform documents such as the National Research Council's (NRC, 1996) *National Science Education Standards* (NSES), and practically all states have adopted inquiry standards. The NSES emphasize inquiry as a content to be learned and a way to learn science. In treating inquiry as a content, the NSES encourage students' participation in activities and learning opportunities that allow them to experience the process of scientific inquiry by posing questions, developing and carrying out experiments, gathering and analyzing results, and communicating findings with their peers. Through this process, they also gain a better understanding of the nature of science and the importance of collaboration and communication in science.

As an approach to teaching and learning science, inquiry-oriented instruction, based on the constructivist theory of learning, emphasizes the active role of students in the learning process. In this model, teachers must pay attention to and access students' prior understanding and experiences, which, in turn, should shape the direction of instruction. Furthermore, teachers need to guide and facilitate the learning experience by allowing students to take an active role in their learning and construct their own understanding through first-hand experience, discourse, and reflection. Assessment plays a critical role in an inquiry-based classroom, because it can help in diagnosing students' prior knowledge, gauging students' understanding throughout the learning experience and guiding instruction, and measuring their understanding and knowledge at the completion of the learning experience.

In order for science education reforms to succeed, it is necessary for teachers to be familiar with and utilize inquiry-based practices in their classrooms; however, this is not the case in many classrooms around the country (Weiss, Pasley, Smith, Banilower, & Heck, 2003). Although, there may be numerous explanations to account for this unfortunate phenomenon, one of the most important reasons to recognize and address is teachers' lack of familiarity with and inability to effectively employ inquiry-based instructional methods in their classrooms. Inquiry-based teaching is simply an abstract idea to teachers who never encountered this type of teaching during their own K-16 education and did not learn to teach in this fashion as part of their teacher education training. Prior studies (e.g. Cronin-Jones, 1991; Hashweh, 1996; Keys & Bryan, 2001; Thompson & Zeuli, 1999; Wallace & Kang, 2005) have indicated that teachers' knowledge and beliefs about (1) science, (2) the learning process, (3) their students, and (4) effective teaching influence their classroom instructional practices. Hence, it is evident that instigating changes in teachers' classroom practices requires a transformation in their beliefs and understanding with regard to the abovementioned areas. Literature on professional development (PD) suggests that such changes, especially improving teachers' understanding of how science operates and use of inquiry-based teaching techniques, can be achieved through effective professional development programs (Bazler, 1991; Caton, Brewer, & Brown, 2000).

Professional development as a tool to enhance teaching is especially stressed in science education reform documents (e.g. NSES) that emphasize inquiry teaching; however, as suggested by prior studies, not all professional development experiences can be defined as successful and fruitful. For instance, Hawley and Valli (1999) propose that short PD models that simply "teach" teachers how to teach through lecture rather than involving them as active participants in the process fail to be effective. It is recommended that PD programs be directed more by the participating teachers and based on teachers' long-term reflections of their own conceptions and practices. Professional development programs should model inquiry-based instruction and allow teachers opportunities to experience science inquiry in an active, collaborative setting and through authentic inquiry research (Loucks-Horsley et al., 2003; Thompson & Zeuli, 1999).

Beginning in 2003, one such professional development program has allowed high school science teachers in a particular Midwestern state to have opportunities to experience science inquiry first-hand and learn about inquiry-based teaching. Several studies have focused on the participants completing this program (Bonner, Lotter, & Harwood, 2004; Lotter, Harwood, & Bonner, 2007). The case-study research by Lotter, et al. (2007) involving the three high school science teachers who participated in a two-week inquiry-based professional development workshop reported on the type and degree of change in four core conceptions: conceptions of science, conceptions of students and student learning, conceptions of effective teaching practices (esp. inquiry), and conceptions about the purpose of education (esp. science education). It also indicated that the type and amount of inquiry instruction performed in the classrooms were both positively and negatively influenced by the participating teachers' core conceptions. Furthermore, these findings alluded to internal and external constraints that impeded participating teachers' implementation of inquiry-based instruction in their classrooms. Some of the key constraints, previously mentioned by Tobin and McRobbie (1996), include a perceived lack of time, the need to prepare students for state exams, and the need to cover all of the material mandated by state standards or school districts.

Purpose

The above case study focused on changes in teachers' core conceptions and the translation of such changes to classroom practices with regard to only one specific course for each participant. The instructional practices of the study's three cases and the core conceptions that were found to influence their instruction fell into three categories: 1) teacher-guided inquiry and few instructional changes, 2) real world inquiry-based units and reflective teaching, and 3) controlled inquiry and cautious change. It would be valuable to extend these findings by exploring other program participants' core conceptions and instructional practices and whether they fit any of the mentioned categories. The current study focuses on a participant attending the same professional development program two years later whose teaching assignments included three different courses. The aim of the study is to explore the changes in the core conceptions and instructional practices of this teacher with regard to all three courses. Furthermore, factors that aid or inhibit the implementation of inquiry-based teaching in these different courses are examined.

Methodology

Context of Study

Beginning in 2003, a group of science and science education faculty at a large Midwestern university took part in a collaborative effort aimed at improving K-16 science education. One component of this multi-tiered project, which was funded by a Howard Hughes Medical Institute grant, included an inquiry-oriented professional development (PD) for high-school science teachers from across the state. The PD consisted of a two-week summer workshop and three follow-up workshops during the academic year. The summer workshop was divided into morning and afternoon sessions. In the morning sessions, participants actively participated in a variety of inquiry oriented activities and discussions. The first week was devoted to teachers developing a 7-step plan aimed at solving their students' "bottlenecks," which refer to concepts that students have difficulty comprehending (Bonner, et al., 2004; Lotter, et al., 2006). Teachers then developed inquiry-based lessons to address their selected bottlenecks. During the second week, each participant presented their inquiry-based lesson to the rest of the group followed by a discussion in which facilitators and other participants provided feedback on the lessons and ideas about ways to improve them. Each day, participants completed readings on topics addressed in the workshop and reflected on the workshop activities as well as their own learning and beliefs. The afternoon sessions allowed teachers to work in authentic settings alongside assigned science faculty conducting research in biology, chemistry, or physics. Participants also completed daily reflections on their experiences in the labs.

Research Design

The current study is part of a larger, ongoing study exploring the experiences of the science teachers participating in these annual workshops. Since the aim of this study is to better understand the experiences, changes in conceptions and practices, and factors influencing classroom practices of one particular teacher, a qualitative case study approach was deemed most appropriate. This approach allows for in-depth examination of data from various sources in order to provide a rich and holistic description and picture of the particular case (Merriam, 1988). These data sources included: a brief questionnaire on participants' views and instructional practices both before the workshop and during the instructional year, field observations in all three classes several times a week for a period of four weeks during the following academic year, and a semi-structured interview and several informal conversations during the observation period.

Sample

The case in focus, referred to as Seth from this point forward, was a high school science teacher in the same town as the university in which the summer workshops were held. Seth, who had been teaching for 17 years, received his undergraduate degree in geology and completed an M.A.T program majoring in biology. He was teaching College Preparatory Biology (i.e. regular biology), Life Science (remedial, lower level course), and Advanced Environmental Science (Junior/Senior level course) in a school that was one of the few in the state to receive a distinguished Great Schools rating of 8 out of 10. The school has slightly over 1500 students, 83% of whom are white, 6% black, 4% Asian/Pacific Islander, and 2% Hispanic with 21% of the student body eligible for free/reduced lunch. The school enjoys above state average math and English scores. The classes are arranged in a Block 8 schedule with four 85 minute classes alternating every other day. Seth taught two biology and an advanced environmental science class on one day and one biology and two lower level life science classes the next day with each class consisting of 22-27 students. Seth's proximity to the University and the number of different types of courses taught were the main reasons that he was selected for this study.

Data Analysis

Interview data were analyzed using the constant comparative method (Glaser & Strauss, 1967; Denzin & Lincoln, 2000) to identify themes regarding Seth's four core conceptions as identified by Lotter, et al. (2007) and factors that influence the implementation of inquiry-based instruction. Observation logs were analyzed in order to document emergent patterns regarding Seth's instructional practices in the three courses. The process of analyzing the data involved several iterations of reading and coding as well as discussion of themes between the authors to identify patterns.

Findings and Discussion

The following sections describe 1) changes in Seth's core conceptions, 2) changes in his instructional practices, 3) factors that augmented the implementation of inquiry-based teaching in his classroom, and 4) factors that impeded such instruction.

Conception of Science

Seth explained that, although a few of his M.A.T courses had addressed the nature of science to some degree, he had continued to view science mainly as a body of facts about the world around us. He further explained that his own experiences with learning and teaching science had left him thinking about science mainly as terminology, facts, equations, and theories he had memorized or learned superficially, and he admitted that this influenced his actions in the classroom. His main focus had always been on science as a content to be mastered. However, upon completion of the summer PD, he began to view science as more than just facts and unrelated content as described in the following quote:

> I had always known that science was more than just facts, but the classes I have attended and those I taught have caused me to lose touch with many important aspects of science and to overlook them in my teaching. In my classes, facts and terminology were always emphasized, but now I see, and try to help my students see, that science is more than that. It is really about posing questions and solving problems. It is about thinking critically and trying different things and being active in the pursuit of answering questions.

Furthermore, Seth's understanding of the scientific process expanded from a simplistic, unrealistic scientific method to a more cyclical and integrated model of inquiry that involves continued iterations of posing questions, making observations, collecting and gathering data, and analyzing and communicating results. Seth explained that he had always begun his courses by introducing the scientific method and followed that specific protocol in the few labs his students would do in class. He emphasized that, although students' thinking was of great value to him, he had, up to that point, mainly done cookbook confirmation type of labs that allowed little room for obtaining a unique answer. Seth explained:

> Up to last year, my students probably could all tell you the steps of the scientific method. Sometimes I would see some of them struggle with the order of the steps or become frustrated because they did not get the "correct" answer. But now I think back, and I see that students can arrive at solutions to problems in different ways. (Pause) I had taken out the creative and imaginative aspect of science. Even though I had asked my students to always base their conclusions on evidence, I had invariably pushed them to come up with the results that confirm what I had taught them. Now I want my students to think outside the box. I want them to be able to not be scared to state that their results were inconclusive or that their results do not support their original predictions. It is still difficult for them to do that because they are not used to it, but at least now I find myself pushing for that mindset.

This indicates that after the PD, Seth had a more enhanced understanding of the nature of science and the process of scientific inquiry. As a result of PD discussions about the inaccuracy of a rigid and linear model of science inquiry and the idea of the scientific process as fluid because each step may lead to further questions, observations, and experiments, Seth replaced his conception of the scientific method as an inflexible set of rules with a cyclical model of scientific inquiry. These changes make Seth's conceptions of science more consistent with ideas presented in science education reform documents. However, there were some minor inconsistencies in his responses that should be mentioned. Although he indicated understanding science as more than content and the importance of science process skills, he added that this was not the case in all his classes. For example, he explained that in his College Preparatory (CP) biology course he could not and did not emphasize the more accurate depictions of the nature of science and how science is done as much as in his environmental science course. He pointed to the continued importance of presenting facts and content information in that class in order to prepare students for the state exam and college. He further described the current structure of the life science course as also inconsistent with some of the changes he had mentioned. He added that he found it difficult to portray an accurate depiction of the nature and processes of science to these students, because he had not yet incorporated much change into the techniques used for this class.

Conceptions of Students

Similar to his beliefs about science, Seth's conceptions of students also underwent change as a result of the summer PD. Seth admitted that, prior to the PD, he did not take into consideration the unique needs of every group of students and taught all of his classes in the same way without regard for the diversity of learners in his classroom. Because he had always emphasized science as facts and content to absorb and put to memory, he had not paid attention to differences in his students' abilities, learning style preferences, prior experiences, and processes of cognition. As described in the post-PD interview, he began to view students as an important variable in the equation.

> I have come to realize that students are not "blank slates" to be injected with information. They come to my classes with different abilities, experiences, and levels of understanding which I need to acknowledge in my teaching. I have also come to realize how important their prior understanding and experiences are, not only to themselves, but to others in class. There have been so many instances where they have shared something that has been valuable to our class discussions and lessons. Instead of saying 'here is something new, let's learn about it', it's like 'what do we already know about this?' So it is more of an *immediate connection* to their own experiences.

He continued to explain that "students in the regular and higher level courses are capable learners who should be actively involved in their own learning and given the freedom to explore their own questions and discover content for themselves with teacher guidance." Here again, a slight point of conflict in his views was seen as he proceeded to comment: "Of course, students in the lower level classes may be able to do so too but need to be guided more and should be given the tasks to complete and the instructions to follow, because they may have difficulty otherwise." Seth indicated a lack of trust in these students' abilities and a hesitancy to allow them more autonomy in their learning.

Conceptions of Effective Teaching

Seth's new understanding about the role of students in the learning process partly describes his newly formed beliefs about effective teaching. In reference to his old teaching methods, he described himself as "a usual lecturer with frequent worksheets and occasional labs and hands-on experience." When asked about his post-PD views on effective science instruction, he displayed plenty of enthusiasm for the inquiry-based method of instruction and mentioned that he had strayed away from traditional methods.

He also mentioned the importance of "incorporating inquiry opportunities for students to pose questions and investigate them and use science process skills and problem solving skills in order to discover more about various class topics." He placed emphasis on engaging students in the learning process by making learning personal and capturing their attention and interest early in the process. The following quote from one of the informal conversations further clarifies the change in his beliefs regarding effective teaching:

> Making it personal and relevant and capturing students' attention, (pause) that was something that was modeled in a lot of the workshop sessions. Let's say we have a demo, what do we know about what's going on here? So trying to pull out from them the knowledge and you can guide that and add things to it and it becomes a teachable moment based on something they already know instead of saying 'here you go, here is some knowledge'—I think it is more engaging to them, immediately captures their interest, makes it more personal.

He also added:

> I think it's basically getting students involved in coming up with their own questions and directing their own learning and engage them more in the process of the lesson. I think that is most valuable. One aspect that I most like about it is the gathering of common knowledge, in a group. Students find that exciting and empowering a lot of times.

He continued with his emphasis on the importance of engaging students in the learning and the "mind capture" approach, as it had been referred to in the workshops. It was also clear that, in his revised view, lectures played a less important role and were to be limited to discussions that should *follow* active exploration of concepts rather than *preceding* them.

> Capturing their interest is very important, (pause) get them excited about the lesson instead of just me saying, 'here, we are going to lecture on a topic and then now we are going to do a lab on it'. I had always tried to introduce an idea and then do a lab. This PD has kind of changed my idea a little bit (pause) pose a question and have the problem present itself, then do the lab, and then discuss the concept at the end"

Furthermore, he viewed inquiry-based teaching as an investigative approach and defined any learning activity in which "groups of students work as collaborative teams to explore and think through problems" as inquiry. He continued: "In an inquiry-based classroom, students may be presented a problem or an action and be asked to figure out why." The PD workshops heavily emphasized that this type of inquiry could occur outside the walls of the laboratory.

Conception of purpose of learning

The final category of beliefs examined in this study was views about the purpose of learning. In response to questions related to the purpose of learning, Seth described how the PD had "opened my eyes" to realize how in the past he had "incorrectly viewed the purpose of teaching to be for students to gain knowledge that they can use in their future classes and careers they pursue" without much attention to anything besides content. He stated that "scientific critical thinking and problem solving are the two most important goals of science education" and added that possessing these two capabilities "applies to every student's daily life and will continue to be used in adulthood, regardless of direct involvement in science." He emphasized the importance of giving students the opportunity to "learn to do science and think in a way that scientists think—like looking at data and interpreting them without help . . . . to get to a point where they make those judgment calls." Finally, Seth made a comment regarding his CP biology course that indicated he had not yet completely abandoned some of his previous ideas. He described his CP biology course as more content-driven because of the "standards and the state test." He added that it is important that "students come away from that class with knowledge of certain vocabulary, processes, and concepts that they will encounter in their lives, college, or on the state exam."

Classroom practice

The second research question is concerned with the ways in which Seth's four core conceptions translate into teaching practices in the classroom. Field observation and interview data were used to provide a rich description of his classroom practice and evaluate the extent to which his instruction was aligned with science education reform initiatives that call for inquiry-based teaching. When asked about his teaching practices since the PD, he described a continuous process of reflecting on his instruction and modifying lessons and activities to make them more inquiry-based and student-centered. He stated: "Since the workshops, I find myself constantly thinking about changes. As a teacher, I am looking at everything so differently now." Seth indicated that although unable to create changes in every aspect of his teaching or re-do everything he had done so far, he was attempting changes and thinking about aspects he might handle differently in the near future.

> I can't do it (inquiry) everyday, especially with three different classes that I need to teach, but whenever I am really rethinking a lesson that's always in the back of my mind 'how can I do this in a more inquiry manner'?

Observing Seth's classrooms clarified several items. First, the rethinking and tweaking of lessons and activities Seth had mentioned were indeed occurring. Second, there were noticeable differences in Seth's instructional practices, including the incorporation of inquiry-based teaching techniques in the three classes which will be described below. The Advanced Environmental Science course, based on Seth's own accounts and the classroom observation data, was the most inquiry-based class. Students often worked collaboratively in teams. Seth's lectures had been replaced with class discussions, video presentations, and team presentations. Students participated in projects and long-term experiments rather than occasional, brief, cookbook labs, which had been the case previously. One example of a long-term investigation that had been introduced after the PD involved the study of lemna. In previous years, Seth had merely discussed and lectured about population growth, and then the class reproduced a simple lemna population growth laboratory exercise out of the textbook. However, this year, he turned this one-time cookbook lab into a year-long investigation that spanned two semesters and addressed other topics besides population growth, including ecosystems. His description of the project follows:

> This year I wanted to do something different and thought the lemna project might be the best route. First semester we explored the population growth of lemna in a more guided inquiry where I was still the one directing students' attention to the question and gave them some directions for the investigation and data collection. But they were really into it. We were able to address not only population growth but also how to make data tables and show data on graphs. It was very successful! We got some of the best growth curves I have ever seen. Then this semester I thought it would be cool to continue with the lemna population activity and allow my students more freedom this time around. So I used the previous project as a baseline study and had my students think about how the introduction of various things into the environment might effect the population growth of lemna. It has been great! They have really surprised me.

Classroom observations coincided with the last week of the open-inquiry lemna investigation. Students were seen walking into the classroom and going straight to their stations to check on their lemna population and collect data. This time was also used to carry out routine procedures such as adding more of the "contaminant", checking temperature, and adding water. Each team was doing something different in accordance with their investigation design. Seth circulated around the classroom and observed teams at work. Occasionally, he would ask members of a particular team questions about their protocol, observations, or other matters relevant to their study. When in need of guidance, the teams would ask him questions as he listened carefully and in return Seth asked further questions to guide the students, rather than giving them the answers. Seth described his role in the classroom as such:

> It (lemna activity) is an ongoing activity. So at the beginning of each class I wander around as they collect data and solve problems like 'our lemna died what we do?' I try to get them to think and redirect questions. 'OK what should we do?' They pose ideas such as 'mess w/ the concentrations? Let's try with half and see what happens?' So it takes some thinking on your part and not giving them the answer but drawing it out of them.

After their initial period of observation and data collection, students returned to their seats and had a brief chance to discuss their findings and possible next steps with their teams. Seth continued to facilitate discussions. Afterwards, he asked them to begin thinking about how to analyze their data and present their findings to the class. Students worked in their teams to draw graphs, check journal articles for prior studies similar to their own, and discuss conclusions and the implications of their study. Several days were spent on this phase of the project, and then several class sessions were devoted to presentations of the individual projects. Each presentation was followed with a question and answer session in which the audience would pose questions or make suggestions for improving the study, and this would develop into whole class discussions on the implications of the findings. This project was extremely student-driven and engaging. Students were constantly active in exploration, discussion, analysis of data, collaboration, and communication.

Seth also described another project he had developed for this course that had taken place prior to the observation period. He had reflected on and modified the recipe-type forest density lab and created a more student-centered investigation of the successional stages of trees. He describes the forest ecology investigation in this way:

> I had always done the lab in the book, and, although students used to have fun going outside and looking at the trees, I did not think they were thinking much (pause). This time we went out there, and we said 'ok let's pose a problem—how can we figure out what's going on here? Who are the dominant species?' Got some of their ideas, we came back and talked and shared those ideas and came up with pros and cons of each. Came up with ideas that were pretty similar to what we've done in the past, but I felt this year they had a better understanding of what they were doing—whereas in the past they were plugging in numbers into equations and not really understanding what those equations were.

It was evident from the interview and observation data that the most changes had occurred in this class. Seth described his interest in making learning relevant to students and allowing them to experience science firsthand. He also described courses such as environmental science as his "favorite" and "ideal," because they gave him plenty of flexibility to teach in this fashion.

> My ideal classroom would be outside. In some ways my environmental science I tried to make my ideal class. Part of it is because there are not set standard. I try to take them outside and with field trips and look at local resources and ecosystems to make it more applicable and conducive to their lives.

In his biology classrooms, the tweaking and slow process of change and reflection he referred to in his interview were evident during the observation period as well. This class consisted of some inquiry-oriented activities, but Seth mentioned that he had not yet dramatically changed any lab, activity, or unit in this classroom. When asked why he had not yet taken steps to modify this class in the same manner as the advanced environmental science course, he identified the quantity of content material that needed to be covered as the chief factor preventing the more immediate implementation of change.

> With bio you need to cover. So much of it is just vocabulary and the concepts behind the vocab. There is a time limit. Not easy to do long-term experiments. You feel like you *have* to cruise through the material/units quickly, so you have to modify the inquiry.

This is not to say that he did not reflect on or change his instruction at all. Instead of large, sweeping changes, Seth had resorted to changing small components of the course, such as doing more class discussions in place of lectures, using attention-grabbing demonstrations or discrepant events, posing problems to engage students in the learning, and asking more questions during activities and class discussion. As he put it, "a lot of it is not changing the lab, but how I *present* the lesson and the topic—for example, brainstorm before we start. Regular lesson, but *they* introduce it." Although there were greater instances of teacher-directed instruction in this class, Seth attempted to maintain his facilitator role during student activities. He also gave students the opportunity to share and discuss the results of the labs and activities instead of simply doing the activities and moving on.

As for Seth's third course, there were little to no changes in the life science classes. There was little inquiry-based learning occurring in this class, and it continued to be dominated by teacher-led lectures, occasional cookbook labs, worksheets, and bookwork. When asked about the life science course, Seth explained that he had spent the least amount of time changing that course. Since the workshops, he found himself thinking about his teaching mainly in the other two courses. He continued: "maybe it is because I am used to using the set activities from before that are shared with the other instructor teaching the same course." Other possible reasons for the lack of change in this course will be described in a subsequent section.

Seth had, however, included some demonstrations to catch students' attention and interest. For example, when discussing osmosis and diffusion, he did a demo that involved placing an egg in three different solutions: water, vinegar, and corn syrup. He also occasionally utilized video clips of Bill Nye the Science Guy and other educational videos to partially replace his lectures. However, there was little change in terms of the students' role in the learning process. They continued to play a passive role in the learning process in that they were most often observed listening to Seth, watching videos, and taking notes. They did work in teams for their labs, but this teamwork did not involve much collaboration or communication, and the conversations that did occur were usually about procedural details. There were hardly any discussions of the steps being carried out or the data gathered. Collaboration was not extensive; in most teams there were some students who were participating less than others. Collaboration was limited to following prepared steps, reading out loud the instructions, copying down the data, and cleaning up. There were few or no questions for students to think about and discuss to guide their learning. Seth did try to facilitate team discussions, but these were limited to procedures and observations. A significant portion of the teams' results were confirmatory of his lectures and the textbook information. As a result, students often simply repeated his statements or regurgitated information from the textbook.

One such example occurred when students looked at some slides of cells under the microscope. This lab was prefaced with reading the textbook section on cells and a lengthy lecture with transparency slides of plant and animal cells and cell organelles. When students were looking at the slides under the microscope, they simply scribbled a drawing of the slides without much discussion. They were often having off-topic conversations about their personal lives, other classes, and so forth. There was hardly any discussion of their observations, the differences between the types of cells, or the organelles. The only recognizable features of the cells in their drawings were the cell wall, the cell membrane, and the nucleus. In addition, most students copied down a few other lines or shapes that they struggled to label. When Seth approached one of the teams and inquired about their drawings, students began checking their lecture notes in order to point to and name the organelles that they had observed. His conversations with the teams were very limited and brief.

Factors promoting change

Seth was cognizant of the changes that had occurred in his core conceptions and the ways in which that was beginning to take shape in his teaching. He also repeatedly mentioned that his understanding of the processes of teaching and learning, especially inquiry-based instruction, had been enhanced as a result of his participation in the PD.

> I just feel very good about the PD. I learned a lot, more than I can describe. It will take me some time to be able to digest all of it and apply it in my classes. Like I said before, I am finding myself thinking about my teaching all the time. I am incorporating some changes here and there, and, even though it may not be much, I have learned so much!

Similar to the participants in the Lotter et al. (2007) study, Seth cited numerous aspects of the PD experience that he had found beneficial to enhancing his understanding. He felt several features of the two-week summer workshops were especially valuable. First, the workshops modeled effective instructional methods rather than just informing participants about them. Seth noted, "It was nice not to be told or trained on what to do but rather shown by the action of the facilitators themselves. It was more powerful that way." Similarly, he found it immensely useful to be an active participant and experience inquiry-based learning first-hand.

> I felt like my students. I was doing things in this workshop rather than being given lots of information. We went out and made observations, we did the inquiry activity with the bread facilitated by the science facilitator, and so forth. I found myself constantly thinking and active. We then put to use the information we had gained about inquiry-based teaching and looked for ways to change one of our current lessons. I could not imagine participating this much and applying my knowledge so quickly.

He also discussed the importance of being in a group of peers and having ample opportunity to discuss ideas with them. He found the large and small group discussions and conversations "very stimulating and encouraging." Finally, he considered the readings, activities, and discussions regarding the inquiry process especially useful, because "gaining a better understanding of the process of science meant that I would also try to portray science more accurately in my classes and would also try to have my students' learning mimic inquiry." He added:

> Learning about inquiry-based learning and all the other stuff we learned wouldn't have made a difference if we had not addressed our misconceptions about the scientific inquiry process first. I used to drill the scientific method into my students' head. My teaching of science was dry and linear and mimicked the unrealistic scientific method rather than the more accurate model of the inquiry wheel that we learned about.

Seth also discussed the importance of the second portion of the summer workshops, the research experience. He felt it was extremely interesting and valuable to join science research laboratories and to work alongside science faculty and graduate research assistants. He mentioned that he thought the afternoon sessions "complemented the morning activities and discussions" by allowing participants to "see and experience science inquiry first-hand." He noted the experience equipped him with a better understanding of science content, investigative techniques and equipments, and the process of doing science.

> Although I like to stay up to date with information in my field, I found much of the stuff I experienced in lab very interesting and eye opening. I had no clue about some of the procedures or equipments. It was so different to see these scientists in action and to have some part in their work during that short period of time.

The experience also allowed him to be more cognizant of his students' experiences in science.

> This was a great way for us teachers to step out of the teacher mode and see things from our students' perspective. At times when I couldn't understand what was going on around, I could totally sympathize with my students. Do they understand when I am lecturing them or is the information just way beyond them? At other times, I found myself thinking 'how can I do this in the class' or 'how can I apply this to my teaching so that my students get to enjoy their experience and learn from it as I am'.

Finally, he noted the importance of the experience in helping him to better understand the value of working collaboratively and communicating effectively. They were able to "bounce around ideas, share frustrations, and explain things to each other." He added:

> It was great to see the collaboration amongst ourselves and also the scientists that we were observing or working alongside. I used to have my students work in teams but not enough and not effectively. I am hoping I have gained a thing or two in the PD.

At the time of the post-PD interview and class observations, Seth had already participated in one follow-up workshop. He felt the follow-up session had been necessary. He indicated that going back to the schools and trying to implement the lessons learned in the summer was not an easy process and expressed gratitude for the opportunity to discuss those experiences with his peers. The sharing of lessons and the stories of successes, failures, struggles, and means of coping with the difficulties was cited as extremely valuable. He referred to the significance of feeling a sense of community that allowed members to benefit from sharing experiences, ideas, and feedback.

> It was just fabulous. We got a chance to come back and just talk for a while and discuss what we had done and what it had been like. It was amazing some of the similar situations we had experienced. It was also great to share how our lessons went and share other lessons we had come up with.

Seth also found the additional inquiry activities that were modeled in the workshop to be a good refresher of the summer workshop. One such activity Seth referred to was the modeling of the 5E learning cycle that involved investigating the process of burning a candle and factors that affect the rate at which that occurred. Seth added: "The candle activity allowed me to see 5E as a model of inquiry teaching that we had learned about. This process made sense, and I got to understand it even better because I was experiencing it like a student."

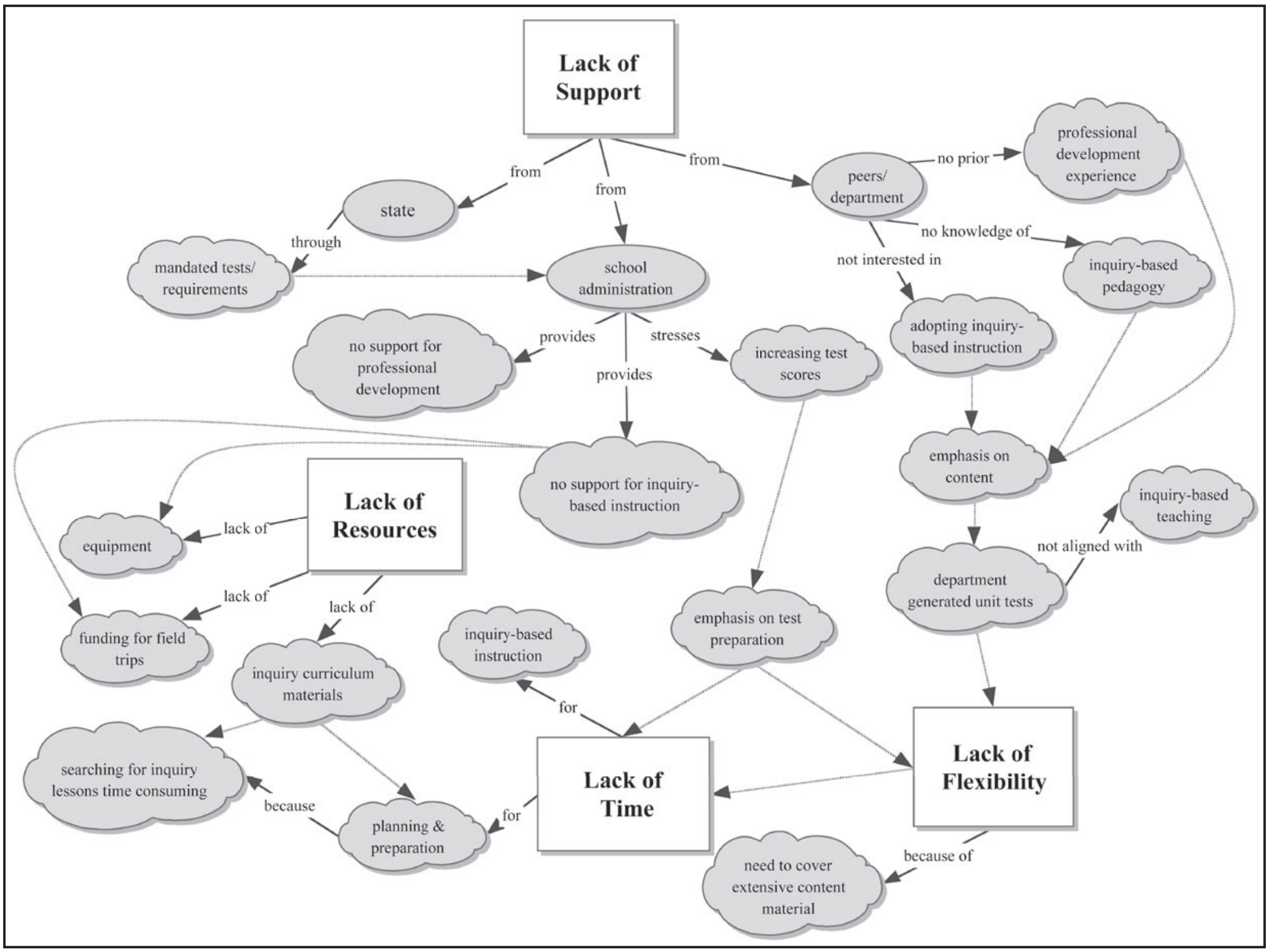
Constraints to inquiry teaching

As noted above, Seth's views and core conceptions had undergone major changes as a result of the PD, but the implementation of inquiry-based teaching in his classrooms was not as obvious nor as consistent. During the course of the interview and informal conversations, Seth alluded to several constraints and offered a number of explanations for not incorporating more changes and doing so consistently in the three courses. Figure 1 provides a depiction of the four main factors and explanations: 1) lack of support, 2) lack of time, 3) lack of resources, and 4) lack of flexibility and the interconnections between these four factors.

The overarching factor that directly or indirectly influenced many other areas was the lack of support that Seth described having from his peers, the department, school administrators, and the state. Seth explained that state mandated tests and requirements had caused a series of practices and requirements at the district and school level that inevitably had made teachers, such as Seth, feel a lack of flexibility and autonomy in their classrooms, especially those such as CP biology, which has a state-mandated exit exam. Seth expressed feeling overwhelmed by the amount of content to be covered in the course as well as the need to prepare students for the state test and the end of unit tests that were created and used jointly by all biology teachers at the school. The inflexibility paired with "a dearth of available inquiry-based curriculum material" caused him to feel as though he had an insufficient amount of time available for both the planning and execution of inquiry-based lessons.

> I have tried looking for inquiry lessons to no avail. It is time-consuming and often unproductive. I just do not feel I have the creativity, energy, and the time to do more than a few inquiry-based lessons at a time or bring about more changes than

Figure 1: Four main constraints to implementing inquiry-based teaching



> I have. It is just too much to try to do, and I have really tried.
>
> I have to be honest that my lower level bio class is getting the least attention this year as I try to change my teaching. I have a hard time finding the time to change the other two courses, and so I find myself not paying as much attention to changing this class and resort to the old material I already have preplanned. Maybe next year I can spend more time on this course too.
>
> In my bio class, I just try to tweak here and there and do some inquiry whenever I can, but I just feel that it is very hard to do in that class, because I don't have enough time to cover everything. All the biology teachers give the same test at the end of the unit, and, no matter what I do; I need to make sure my students are ready for those tests. There is hardly any time to do long-term projects and investigations.

Besides the lack of resources for planning inquiry-based teaching, there was also a lack of resources for carrying out inquiry-based instruction. For example, microscopes had to be shared by three different classes, other equipment and materials needed for various activities and projects were not available, and there was no funding to purchase such resources or pay for requested field trips.

> Even in my environmental science, I feel I could do a whole lot more if I had the funding for purchase of equipment or to fund a field trip or two my students and I have been interested in taking. At least I can take them outside and use the areas around school to explore, but I really feel the lack of resources in the other two classes.

Finally, Seth felt a sense of isolation and frustration, because he was the only one in his department who had undergone the PD experience, knew about inquiry-based learning, or cared much for it. He felt that he did not have the necessary support from his peers to be able to collaborate and bring about changes on a wider scale to science instruction in the school. This lack of support also led to other issues already mentioned above such as the overemphasis of content and pressure to prepare students for school and state exams.

Conclusions and Implications

This case study provided further support for the need for effective inquiry-based professional development opportunities for teachers in order to bring about the changes in their views and practices needed to enhance students' science learning experiences. As noted in earlier studies (e.g. Huberman, 1995; Lotter et al., 2007), changing teachers' views and instructional practices is a slow and intricate process that is dependent on a variety of factors, as has been illustrated to some degree in this study. Seth's case further demonstrated that professional development experiences should 1) occur over an extended period of time, 2) involve active participation of teachers by immersing them in authentic scientific inquiry, inquiry-based activities, and discussions, 3) model effective inquiry-based instruction, and 4) allow teachers opportunities for continuous reflection on their beliefs and practices during the PD and in their classrooms in order to identify areas that could be improved upon and implement the necessary revisions. There is also an immense need to provide PD participants the means for continued communication and collaboration in an effort to 1) share ideas and inquiry-based lessons, 2) discuss frustrations, obstacles, and successes faced during the implementation of inquiry-based instruction, and 3) facilitate communal reflection on ways to further enhance students' science learning experiences.

Beyond the PD specific components, Seth's case illustrated numerous additional factors in the school environment that influence the implementation of inquiry-based instruction, and, therefore, require serious consideration. One such factor is the state-mandated tests and requirements that put extra pressure on schools, some of which, as illustrated in the case of Seth, place tremendous emphasis on testing and coverage of content material that allows little flexibility and time to plan and carry out inquiry-based lessons. Additionally, in an effort to increase test scores, little attention is given to professional development for teachers and, the promotion of inquiry-based instruction is virtually nonexistent. Furthermore, science teachers in their department are often instructed to keep their instruction the same, especially in the core courses that students get tested on, and administer the same end of unit exam for all sections of a course. These exams, along with the state mandated tests, often overemphasize content and vocabulary and are often unaligned with inquiry-based instruction that PD participants wish to incorporate in their classrooms.

It is imperative that school administrators realize the power of inquiry-based learning in enhancing student learning and science experiences. The emphasis on testing and content-driven curricula must be replaced with an emphasis on the augmentation of student learning through experience in order to develop a science literate student population as defined by the NSES (NRC, 1996, p. 22). School administrators must play an active role in encouraging inquiry-based teaching and learning in all aspects of the school by providing teachers with the encouragement and support necessary for participation in professional development and implementation of inquiry-based instruction.

In addition to the lack of flexibility and time for inquiry-based instruction, the scarcity of time available to devote to creating and planning inquiry-based lessons makes achieving these goals extremely challenging. Truly, inquiry-based curriculum materials are scarce, and many teachers, such as Seth, find it difficult, time-consuming, and sometimes unproductive to undertake the process of converting to inquiry-based instruction. The science education community must strive to equip teachers with inquiry-based curriculum materials and aid teachers in finding resources and planning out their own lessons and units. Teachers who participate in PD experiences may find themselves struggling to concomitantly meet school requirements, adopt inquiry-based instruction, and create a community of change within their schools. In order for these teachers to be successful, they must be provided assistance along the way in the form of peer and expert coaching (Fullan & Stiegelbauer, 1991; Thiessen, 1992).

Another underlying issue is the lack of support and the sense of isolation PD teachers feel when they return to their schools and find themselves surrounded by colleagues who may not be familiar with inquiry-based learning or have no interest in non-traditional methods of teaching. Several steps, in addition to continued communication with the PD facilitators, must be taken to alleviate this sense of isolation and helplessness. First, PD facilitators should encourage and assist participants in finding a means of staying in communication with one another upon their return to their schools. This could be done by arranging group meetings or through social networks. Services such as Twitter and Facebook or online discussion forums provide a convenient, low-cost medium through which members can stay abreast of group activities and share lessons, ideas, problems, and so forth. These communities could even be extended to include other teachers, from across the country, who have gone through similar experiences through the formation of critical friends groups. Second, many of the previously mentioned obstacles may be eliminated if PD planners focus on teachers from the same schools or districts so that they are all equipped and better prepared to promote and instigate changes in science instruction once they return to their buildings. Moreover, this will enable these teachers to work collaboratively in planning lessons, creating assessments that are aligned with the curriculum, receiving feedback on their instruction from each other, and discussing issues and obstacles that they may continue to face. Focusing on "communities of practice" and building a "professional culture" allow for supportive and nurturing environments that are key to the adoption of inquiry-based and effective instructional practices (Loucks-Horsley, et al., 2003, p. 91). If the ultimate goal is to better prepare a science literate citizenry, we must begin our work by not only enhancing the instructional capacity of teachers through effective professional development, but also by calling attention to the culture of the educational institutions to which they return and needs that may arise after the PD experiences.

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