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By: **Rachel E. Wilson** and Julie M. Kittleson

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Abstract Science education researchers are concerned with preparing pre-service elementary teachers (PSETs) to teach in ways that support students to learn science in a meaningful way. Preparing elementary teachers to teach science is complicated given that they tend to be generalists and may not have the same experience with science as secondary teachers. During an elementary science methods course, we explored PSETs' perspectives on the teaching and learning of science via a case study that included four PSETs. Using Frykholm's (Journal of Curriculum and Supervision 19:125–149, 2004) framework of 'educative' and 'debilitating' discomfort, we examined PSETs' approaches to their own science learning and their approaches to science teaching. A theme apparent in PSETs' perspectives was struggle. We described ways in which struggle was either educative or debilitating for PSETs, both in terms of their own learning and the ways in which they approached teaching. Some PSETs who struggled in their own learning developed learning experiences to engage their students in reform-based science teaching, while some PSETs developed learning experiences that prevented their students from experiencing any sort of struggle in their learning process. The ways in which these students dealt with their own learning struggles mirrored the ways in which they dealt with their struggles to become teachers of reform-based science instruction. Helping PSETs to deal with their feelings of discomfort with science content or ideas about the nature of science learning and teaching promoted by reform documents may be a key issue in developing their willingness to become facilitators of meaningful science learning.

Keywords Teacher education · Elementary science teaching · Preservice teachers · Reform based teaching · Struggle · Discomfort

R. E. Wilson (✉) · J. M. Kittleson
Department of Mathematics & Science Education, The University of Georgia, 212 Aderhold Hall, Athens, GA 30606, USA
e-mail: rewilson2@gmail.com

Elementary teachers have a tremendous responsibility as educators. They are expected to help young students develop a foundation for learning, and they are asked to serve as models for thinking critically and engaging in problem solving. Additionally, most elementary teachers are charged with teaching mathematics, language arts, social studies, and science. This situation is challenging in the sense that all these disciplines have demanding learning goals. In the case of science, reform documents such as the *National Science Education Standards* (NRC 1996), the *Benchmarks for Science Literacy* (AAAS 1993), and *Taking Science to School* (Duschl et al. 2007) have outlined an extensive list of standards for science education. Consider the goals outlined by Duschl et al. (2007): “The eventual goal of science education is to produce individuals capable of understanding and evaluating information that is, or purports to be, scientific in nature and of making decisions that incorporate that information appropriately” (p. 34). Meeting these goals involves helping students *understand* science as a way of knowing rather than simply memorize science content.

Science education researchers have been concerned with how elementary education programs can best prepare pre-service teachers as well-started beginners (Zembal-Saul et al. 1999) and reflective practitioners (Bryan and Atwater 2002; Bryan and Tippins 2006; Davis et al. 2006). Mikeska, Anderson, and Schwarz (2009) described one goal of elementary science teacher preparation as *engaging in science*, or “Finding ways to teach content that is meaningful and engaging to students” (p. 679). Planning for meaningful science learning, however, is challenging. Mikeska et al. wrote that pre-service elementary teachers often translate *engaging in science* as keeping student interest in science activities, and consequently fun becomes the motivating factor in planning. Complicating matters is the issue that pre-service teachers may be placed in settings in which there are limited opportunities to teach science or observe science being taught. High-stakes testing has limited the amount of science being taught in elementary schools (Jones et al. 1999). This situation makes elementary science education pressing because once pre-service teachers enter the teaching profession they may have fewer opportunities to further develop ideas about science teaching relative to math and literacy. Therefore, the issue at hand involves encouraging pre-service elementary teachers to implement science instruction that guides their students to understand science in ways described by people such as Duschl et al. (2007).

During an elementary science methods course, we explored pre-service elementary teachers' (PSETs) perspectives on the teaching and learning of science. A theme that became apparent in PSETs' discussions of science teaching and learning was struggle. We argue that struggle is a window into PSETs' perspectives on how to structure learning experiences for the goal of *understanding*. The task being asked of PSETs—to teach science in a meaningful way—is inherently complex; struggle helps make sense of PSETs' orientations to science teaching because it serves as a platform for reflecting upon their own experiences with science as well as for investigating ways in which they recognize the impact of instruction on their students' developing understandings. The focus of this paper, therefore, is to explore how PSETs conceptualize meaningful learning and their roles as teachers. In this way, we as science teacher educators can better understand how to prepare PSETs in ways that help them think about designing instruction that is consistent with reform documents.

Relevant Literature

Teaching science has many demands. For example, teachers are expected to orchestrate learning experiences by being responsive to students' ideas and guiding students' thinking.

Teachers may encounter situations in which they are not immediately sure about how to respond to students' ideas. Yet one aspect of being a teacher involves figuring out how to resolve such situations, and resolutions may require teachers to sort through their own understandings of science concepts and the nature of scientific knowledge. Struggling to sort out one's ideas can lead one to understanding. Helping students work through their ideas can help them, too, construct understandings. Again, sorting out one's ideas is a demanding activity, and it is one in which struggle is illuminating.

We considered the following issues when investigating PSETs' perspectives on science teaching and learning: a vision of elementary science teachers are asked to embrace, a description of challenges associated with elementary science teaching, and a perspective on facilitating understanding in the elementary classroom in a way that aligns with the vision of elementary science. Alongside these perspectives we discuss the idea of struggle. We believe that struggle can reveal challenges that PSETs face in aiming to meet the goals of science education and how we as teacher educators might better prepare them to meet these goals.

Vision of Elementary Science Education

Reform-based science instruction has called for teachers to present elementary-aged students with authentic science experiences. The *National Science Education Standards* (NRC 1996), as well as the *Benchmarks for Science Literacy* (AAAS 1993), indicate that teachers should provide elementary students with first-hand knowledge of the characteristics of science. This includes, but is not limited to, having students use observations as evidence to support inferences, ask scientific questions and figure out ways to go about answering them, develop skills used by scientists to test questions and gather data, as well as discuss the nature of scientific knowledge. This vision of science in elementary school asks elementary teachers to structure more sophisticated learning experiences than is often thought appropriate for elementary learners. The stereotypical idea that elementary science students have difficulty in understanding abstract concepts and the ideas of control and inference in experimental learning may encourage the development of more simplistic learning experiences, yet research has shown that elementary-aged students are capable of participating in epistemologically sophisticated science activities (Smith et al. 2000; Metz 1995, 1997). Therefore, more meaningful science learning at the elementary level seems possible.

Duschl et al. (2007) reviewed science education research on best practices for the teaching of science that support the ultimate goal of understanding and evaluating scientific information, which included: involving students in scientific practices and scientific inquiry, as well as encouraging discourse and discussion to encourage the use of evidence in explanation. This type of teaching encourages students to come to a first-hand understanding of science rather than simply to develop knowledge of science. Therefore, a constructivist vision of science education advocates the development of understanding, rather than simply knowledge accumulation.

Challenges Associated with Elementary Science Teaching

One of the challenges for elementary teacher educators is to prepare PSETs to be facilitators of science learning that leads to understanding, rather than to be teachers of scientific knowledge. In taking up constructivist teaching, Windschitl (2002) has argued that science teachers face pedagogical dilemmas that require them to focus on "new dimensions of instructional expertise", which included: student understanding as the focus of classroom practice, managing classroom interaction and discourse, understanding content, and assessing students' knowledge (p. 143). All four of these dimensions of instructional expertise are related to implementing inquiry-based experiences in science classrooms. PSETs likely have not experienced science as inquiry, which makes teaching via inquiry challenging (Davis et al. 2006; Davis and Smithey 2009; Metz 2009; Schwarz 2009; Zembal-Saul 2009). An experiential understanding of science as inquiry may be a factor in being able to make connections between content standards and how to teach them in an authentic way to achieve a more experiential understanding and less knowledge acquisition. Therefore, PSETs' science subject matter knowledge is central to their ability to facilitate science learning that addresses Windschitl's (2002) "new dimensions of instructional expertise" for constructivist science teaching.

One example of the significance of subject matter understanding in elementary teachers is drawn from the mathematics education literature. Using a scenario of a teacher working with students to develop a model of why you move the decimal place when you multiply decimal numbers, Ball et al. (2001) have written that in order to teach mathematics as more than just procedures, teachers must understand the complexities and subtleties of mathematics topics. In order to teach conceptually based mathematics, teachers need to have confidence in their own knowledge of the topic in order to respond to students with different developing understandings. In the scenario, Ball et al. (2001) wrote that the teacher had to "be able to reason through her confusion as the lesson unfolded so she could keep the lesson on track" (p. 440).

> Being able to manage the confusions into which students stumble, to keep one's mathematical bearings, to have a sense of the relationships between the multiplication of whole numbers and the multiplication of decimals, and to be skillful in putting the base-ten blocks into flexible use—each of these activities requires particular kinds of mathematical knowledge and ways of reasoning (Ball et al. 2001, p. 452).

Ball et al. argued that part of pedagogical content knowledge for teaching mathematics is more than simply knowing procedures; it requires having an understanding of their subject matter in order to deal with common student difficulties.

It seems reasonable that if we want PSETs to be able to manage science learning environments so they can respond to the problems and confusions of students within an authentic learning environment we need them to understand the complexities and subtleties of science topics, have confidence in their knowledge of science, and be able to manipulate and feel comfortable with scientific equipment. While PSETs have been shown to have some declarative knowledge of central science concepts in elementary science curriculum, their conceptual understanding of such science concepts may not be adequate for dealing with common misconceptions of students (Atwood and Atwood 1996). Therefore preparing PSETs to take on a role of teacher as facilitators of science learning and developers of conceptual understandings is a tall order when elementary preparation programs are without comprehensive content preparation in science (or in all disciplines of science) and (usually) only one methods course, in addition to having little support for teaching science in schools. "Changing practice is primarily a problem of learning, not a problem of organization. Teachers who see themselves as learners work continuously to develop new understandings and improve their practices" (Peterson et al. 1996, p. 148). Preparing teachers who see themselves as learners, as individuals involved in the development of their own understanding of science and teaching science, could help them to think about their role as teachers in guiding students in making sense of science concepts.

Facilitating Understanding in Elementary Classrooms

Rather than through a handing-down of knowledge, a goal of understanding in science education puts the teacher in a position of a facilitator of learning. Mortimer and Scott (2003) argued that if our goal in teaching is to develop in students an understanding somewhere between everyday conceptions of science phenomena and scientifically accepted explanations of phenomena teachers need to incorporate dialogue as a consistent element in their classrooms. “Meaning making can be seen to be a fundamentally *dialogic* process, where different ideas are brought together and worked upon” (Mortimer and Scott 2003, p. 3). The role of teacher is therefore to orchestrate learning experiences, be responsive to students’ ideas, and guide thinking in experiential learning situations. It may be that teachers use hands-on activities, but the nature of hands-on activities in a dialogic setting versus a discovery learning setting are quite different. Rather than simply looking at the language that PSETs used in describing hands-on activities, we felt it was important to pay attention to the implementation of hands-on activities and the role that the PSETs played within the learning experience in order to determine whether the teacher was a facilitator of learning or was merely providing opportunities for students to play with materials.

Because reform documents encourage teachers to engage students in sophisticated learning activities, it is useful to examine how dialogic learning influences the implementation of a learning activity. Bingham (2005) used a metaphor of rolling dice to illustrate how to think about managing such a learning environment that requires balancing teaching towards standards and allowing students to engage in learning in authentic ways. When we roll dice the variety of outcomes are limited or bounded by the numbers on the dice, but we do not know the combinations that will unfold. Bingham (2005) argued that aiming to engage students in an authentic learning environment we need to think of the teacher and student involved in a game of rolling dice, with the teacher encouraging the student to continue to roll the dice, to be involved in questioning, exploring, and making connections until the concept is exhausted. “It is the educational engagement of teacher and student that must keep the question (the dice) in play for as long as the subject matter at hand requires a questioning attitude” (Bingham 2005, p. 558). Bingham (2005) noted that in an era of standards-based curriculum, there will always be a tension between a teacher feeling the need to direct discussion and trying to open up dialogue so that understanding can develop in a more authentic way. Therefore, in a dialogic implementation of hands-on science activities, the role of the teacher as a facilitator is to continually examine whether the balance between standards and authentic science learning is being achieved by paying attention to students’ developing understandings.

Teaching within reform-based curricula that supports inquiry methods and the development of problem solving skills over facts and procedures introduces an element of “terrible freedom” (Atwell 1991) for teachers because they are being asked to “start teaching based on what children are thinking and doing” (Villaume 2000, p. 21). This type of constructivist teaching can be uncomfortable for teachers because they are being asked not to deliver set information to students, but rather to engage with students in the learning process, which challenges notions of their roles as teacher, beliefs about the nature of the disciplines they are teaching, and requires a deeper understanding of content information (Frykholm 2004). In a case study of teachers experiencing the implementation of a reform-based language arts program, Villaume (2000) found that “uncertainties that were tolerable and even stimulating for some proved to be intolerable and frustrating for others” (p. 23). Frykholm (2004) also found that mathematics teachers implementing constructivist education reforms experienced different domains of discomfort, which led to development of a theoretical framework "through which to pursue greater understanding and exploration of the notion of teacher discomfort" (p. 127). Frykholm's (2004) exploration of teacher discomfort through observations and interviews of twenty-five teachers in three states led to descriptions of various domains and dimensions of discomfort that were interpreted as being either 'debilitating' or 'educative' for the teacher. Frykholm (2004) described *debilitating* discomfort as experienced by teachers whose beliefs about teaching and learning, the appropriateness of curricula, or adequateness of their own content knowledge conflicted with what was being asked of them as teachers of constructivist, reform-based curricula. In comparison, teachers who illustrated *educative* discomfort were those who were able to "tolerate discomfort", and in some cases, use it as a "pedagogical tool" (Frykholm 2004, p. 146). Regardless of teachers' comfort with their own content knowledge, as long as they believed that "uncertainty is a necessary and natural component of learning" and their beliefs about teaching and learning aligned with curricula, they were able to help their students move towards deeper understanding of concepts (Frykholm 2004, p. 146)

Frykholm (2004) has written about the usefulness of exploring discomfort because of the implications it has for teacher education and preparation:

> …if teachers are expected to embrace a philosophy of mathematics teaching and learning that no longer rests on a foundation of certainty (that is, to model problem solving and to welcome divergent thoughts and strategies), then educational leaders certainly must endeavor both to understand the kinds of discomfort that will emerge for these teachers and students and to help them work through such discomfort (p. 130).

This framework of *educative* and *debilitating* discomfort that Frykholm (2004) described was useful to us in thinking through the discomfort our PSETs expressed to us about teaching science, a content discipline that they were nervous about teaching, as well as a subject they often explained that they struggled with as students. We used Frykholm's (2004) descriptions of *educative* and *debilitating* discomfort because they helped us make meaning of the ways in which the PSETs were describing teaching and learning science.

The participants we highlight in this article were chosen to illustrate the usefulness of Frykholm's (2004) theoretical framework in thinking about how PSETs are interpreting reform-based science curricula and the consequences for the ways in which they talk about science teaching and learning. The participants we highlight as examples of *debilitating* discomfort were the ones who tended to plan science learning experiences that trivialized learning and negated the active role of the teacher in facilitating learning. Whereas the participants we highlight as examples of *educative* discomfort were the ones who may have used language associated with discovery-based learning, but in fact showed evidence of reflecting on their role as teachers in facilitating science learning experiences that looked more dialogic. In using this theoretical framework of *educative* and *debilitating* discomfort, we are choosing to highlight students who we feel best represented these categories as a way to think through the implications for teaching PSETs who often embody both types of discomfort in learning to teach science.

We recognize as a science education community that we want our science teachers to be able to manage the developing ideas of students in inquiry situations. Yet we recognize that teaching science is not just an issue of content knowledge; teachers need to be willing to be learners and to see why their own struggles and the struggles of their students can be a productive part of learning. Helping students make sense of things sometimes involves struggle; however, allowing them to struggle may be a way to demonstrate to them that they can resolve unfamiliar issues. Instead of seeing struggle as a negative outcome in the learning process, struggle may simply be a part of problem-solving. Along these lines we used Frykholm's (2004) framework of educative and debilitating discomfort to examine ways in which preservice elementary teachers discuss their own science learning experiences, their beliefs about teaching and learning science, as well as their discussion of the role of struggle in learning. More specifically we asked: How do the science learning experiences of PSETs influence their ideas about how to structure meaningful science learning experiences for students? We describe how four PSETs characterized their previous learning experiences, particularly with respect to struggle, as well as how these experiences may have influenced their ideas about science teaching and learning the role of hands-on activities in science teaching and learning.

Method

In the following section, we describe the context in which this research was conducted, the participants, the data sources, and the data analysis.

Research Context

This qualitative study involved PSETs enrolled in a science methods course at a large research university in the southeastern United States. The Early Childhood Education program at this university involved a four-semester sequence of courses. The participants in this study were in their last year of an undergraduate program; pre-service teachers took science methods the semester prior to student teaching. In addition to science methods, pre-service teachers took methods courses in literacy, mathematics, and social studies as part of the Early Childhood Education program. Additional courses associated with the program included courses focused on issues associated with teaching in the elementary grades (e.g., instructional planning, assessment, diversity) and mathematics content courses specifically designed to complement the mathematics education courses.

During the semester in which this study was conducted, pre-service elementary students were involved in a one-month field experience in local elementary schools. For 4 weeks (5 days a week) during the middle of the semester the pre-service teachers reported to their field placement classroom rather than to their university classes. Following field experience, pre-service teachers returned to their university classes for the remainder of the semester. With respect to science teaching, the pre-service teachers reported seeing little science in their field placement classrooms.

Participants

All participants were in the same elementary science methods course. There were 27 students enrolled in this course (1 male; 26 females). Twenty-two students consented to participate in this study; data were collected on all students who consented to participate. In this study, we focus on four pre-service teachers: Analeigh, Sharon, Reagan, and Angela. Using purposeful sampling, we chose these students as participants because their perspectives were illustrative of a continuum of beliefs and experiences described by other pre-service teachers in the course. These participants were similar in the sense that they were all white upper/middle class females who were of traditional college age. They tended to be successful students, as their admission to the university and the elementary education program was very competitive.

Data Sources and Analysis

We selected a case study approach for this investigation. According to Yin (2009), case studies are appropriate when the intention is to develop an in depth understanding of a phenomenon and to understand the pertinent contextual conditions. In terms of the unit of analysis—in this instance, the entity that comprises the case—we selected a single-case study in which the 4 participants comprised the case. More specifically, this case was considered a *particularistic case study* (Merriam 1998) in that it focused on a particular situation or phenomenon. According to Merriam (1998), a particularistic case study can be used to "examine a specific instance but illuminate a general problem" (p. 30). The focus of this study involved exploring how PSETs' experiences with science learning influenced their beliefs about learning and teaching science. Elementary teacher preparation tends not to require the same level of science content background as middle or secondary preparation programs. Thus, it is important to consider how PSETs' relatively limited experiences with science influence their ideas about science learning and teaching. Since science instruction at the elementary level provides students with a foundation for future science experiences, it is worthwhile to examine how elementary teachers negotiate issues associated with teaching for meaningful science learning. Therefore, insights from examining these PSETs' approaches to science teaching and learning have implications beyond this case.

A case study involves collecting multiple sources of information. Participants were interviewed twice, once at the beginning of the semester (I-1), and the second interview (I-2) occurred after participants had completed the one-month field experience in an elementary classroom. The first interview was designed to elicit PSETs' conceptions of science teaching and learning; the second interview was designed to capture their approaches to teaching and their reflections on their teaching within elementary classrooms. The second interview also allowed us to determine if PSET's descriptions of science teaching and learning were consistent with the ways in which they involved elementary students in science learning experiences as evidenced through written lesson plans.

Questions asked in the first interview included, but were not limited to: What are your goals for science teaching? What do you think it means to learn science? What do you think constitutes good teaching practice in science? In what ways do you think this kind of instruction supports learning? Questions asked in the second interview included, but were not limited to: Please describe what you did with science during field experience. What do you think your students got from your lesson/unit? What were your goals for your lesson/unit? That is, what did you want students to learn? If you were going to teach this science lesson/unit again, what changes would you make? How do you think these changes would help you meet your goals?

In addition to interviews, we collected course work from each participant, including, but not limited to, reading response papers that centered around their experiences as students and questions associated with science teaching (denoted as RR-# in findings section), field assignments (one assignment involved interviewing elementary students about their ideas about science, the other involved teaching science to elementary students), and peer teaching lesson plans. These data sources provided supplemental information about PSETs' own learning experiences as well as about their approaches to science teaching and learning.

As a starting point, we used a constant comparative method (Glaser and Strauss 1977) to analyze data collected as part of the case study. We drew primarily on interview data and used additional data sources to substantiate our findings. We read through the interview transcripts and reading responses and noted instances in which participants described struggles they had with learning and with teaching science. We used the experiences of the four participants to construct a description of the ways in which struggle was associated with teaching and learning. Emergent categories included how they viewed their own learning struggles in general and in science in particular, how they viewed science learning, and how they enacted science learning experiences for their students. We used Frykholm's (2004) descriptions of educative and debilitating discomfort to inform the representation in our particularistic case study as we found these concepts to represent a key difference in the way these four PSETs describe their learning struggles and how these struggles are connected to their views of science learning and teaching.

Our intention was to understand how the prior learning experiences of these PSETs influenced their ideas about science teaching and learning. We believe that examining the personal learning *struggles* of Angela, Reagan, Sharon, and Analeigh is central in illustrating their different approaches to science teaching and learning. Further, viewing this case as an instance of a larger phenomenon allows for coming to understand how to support PSETs' efforts to facilitate meaningful science learning.

Findings

Overall, the PSETs in this study were "good students," meaning they tended to have done well in school. That they have made the grades necessary to be admitted to a competitive elementary teacher preparation program, however, did not mean that they had been equally involved in experiences that supported science learning or helped them recognize strengths and weaknesses in their own science understandings. Our four participants had similar views of science teaching and learning. All four described hands-on science activities as good science teaching, as helpful in their own learning, and as helpful for their students. All described using hands-on activities as beneficial to students as it would allow them to "see" the phenomena and thus would help them remember the lesson. This was not surprising, however, as they were all enrolled in an elementary science methods course in which these ideas were being promoted when we interviewed them. Additionally, PSETs said they encountered hands-on activities in other methods classes, such as their math methods class. They indicated that using manipulatives in math could help students "actually see what's going on" (Sharon, I-1).

PSETs' view of good teaching as hands on is one of the issues under consideration. While all participants used language consistent with a discovery approach to learning, they differed in the extent to which they espoused a discovery approach and in the extent to which each person positioned herself as a facilitator of learning. We found that the ways PSETs translated their views of science teaching into practice were not similar. Further, we found a connection between ways in which these four participants talked about their own science learning experiences and their planning of hands-on activities. All four participants admitted to struggling in science, especially disliking science instruction that emphasized memorization. In addition, they all admitted to being "nervous" about teaching science. Yet these PSETs did not think about learning or the teacher's role in facilitating learning in the same way. In particular, some PSETs used their experiences of struggling with science to inform their role as a teacher. We found that grouping the four participants into pairs (Angela and Reagan; Sharon and Analeigh) based on their personal learning experiences illustrates a key difference in the way the participants viewed science teaching and learning, as well as how they viewed the role of the teacher as facilitator. The next section describes key differences between the two groups. It is plausible that PSETs experience both types of discomfort, however, we focus on four PSETs who represented the two categories in Frykholm's (2004) framework to help us to understand how to prepare teachers for the challenges of reform-oriented science instruction.

Cases of Educative Discomfort

Frykholm (2004) found that some teachers are able to tolerate discomfort in their knowledge of content. When teachers' beliefs about teaching and learning mathematics were consistent with the philosophy of reform-based methods, they were more tolerant of periods of discomfort experienced while teaching. We found that the way in which Reagan and Angela responded to their own learning struggles influenced their beliefs about teaching and learning science in ways that were consistent with reform-based science instruction. In the following section, we describe these two students.

Reagan As a former psychology major, Reagan came into the science methods course having taken the largest number of college science courses in her cohort. Reagan cited her experiences in college science classes as some of the most difficult, but also as the most beneficial. "Science has always been a subject that I've enjoyed, but for some reason it has proven to be the most difficult for me academically" (RR-1). She mentioned that time constraints in college motivated her to become aware of how she learned best: "I started mentally noticing what was and wasn't working for me, the classes that I would struggle in. I was like why am I struggling in this? What kind of teacher do I have?" (I-1) In response to her academic struggles, Reagan developed strategies to help her with her own learning:

> I'm very visual and hands-on. I need to see it and I need to talk through it and so that's what I do when I'm by myself I sit there and stare at it, I rationalize it, I don't know, I'm a big explainer too. (I-1)

Reagan indicated that she took responsibility for her own learning, and her learning in science was geared towards mastery: "When something's hands-on, I get to try it, and I go through step one 'til I master that 'cause I can kind of control the pace, because I'm initiating the investigation myself" (I-1). Reagan's experiences learning science were difficult, but she recognized that a teacher's approach to instruction along with her efforts to make sense of the information affected her learning.

Despite her struggles in learning, Reagan discussed how much she ended up enjoying learning by engaging in hands-on activities and how this engagement encouraged her to think about teaching using more hands-on experiences for her students:

> I was so discouraged in those early years [in my own schooling], you know and once I started finding those ways that clicked for me to understand it and doing the more hands-on things…I loved it…the main thing that I want to do in my class is have a hands-on thing, even though it's scary to do experiments with younger kids. (I-1)

Reagan's goal for her students was to have them come to an understanding of science concepts through hands-on activities. She indicated that she wanted to make sure she was "facilitating different types of learners" (I-1) and doing so in a way that she, as the teacher, supported students' learning. In terms of what she hoped to do with her own science teaching, Reagan commented:

> I want to sit down with [my students] at the beginning of the year and figure out what they think about science because I felt, growing up I felt so many times that I could have appreciated science at such an earlier age if my teachers would have just taken, a little bit more effort, you know, and encouraged me a bit more because like I said initially I was so discouraged in those early years. (I-1)

Reagan was aware that a teacher could play a key role in engaging students in science. This perspective, coupled with her awareness of her own learning, put Reagan in an interesting position to reflect on her actions in her field placement classroom. When describing her teaching in a first grade classroom, Reagan noticed in herself the tendency to fall into the role of teacher as imparter of knowledge, rather than a facilitator of learning:

> I noticed in my placement [first grade classroom], there was so much of an urge in me to just say look guys, I'm going to sit down and show you this process, just memorize it, don't ask me why it works…but I'm going to force myself to realize that by me doing that it's impeding on their investigation and their thought process and remember how I always felt limited as a student when my teachers would do that to me, and I'll just let them choose whatever works best for them, so that's my goal. (I-1)

Reagan recognized that teachers not only have to fight against the urge to simply transfer knowledge to their students, but they also have to struggle with issues of time needed to teach in ways she believed were most beneficial to students, and that was being actively involved in their own learning.

One observation we made about all our participants was that they often used terms like 'hands on', 'discover', 'active', and 'choice' when describing science instruction. These terms were not limited to science instruction; participants used these same terms when describing math instruction. Participants indicated that in their math methods courses they were encouraged to allow students to explore: "One thing they're pushing on as a future teacher is allowing for exploration, I've heard that more in the past 2 years with math, you know, don't teach [students] the algorithms, let them figure out what works for them" (I-1). Given the prevalence of the language of discovery, we wanted to know whether this language was indicative of PSETs' approaches to teaching and learning or whether they took a more dialogic approach. In Reagan's case, we noticed that she used some language consistent with discovery, perhaps because she heard this language in various methods courses, but when we examined her case more closely we found that she positioned herself as being responsible for facilitating learning.

Reagan's views of learning and teaching were reflected in the way in which she discussed her time in the elementary classroom during her field experience in a first grade classroom. During field experience, Reagan collaborated with Angela (another participant) on a lesson about light and shadows. She created a center focused on the question "Where do shadows come from?" With respect to students' understanding of light and shadow, Reagan commented:

> Two things I noticed the most that [students] were having the hardest time with were, like, can you hide your shadow, and we were talking about that, you know, what happens when the sun gets directly overhead you can't see it because it's shining right down on it so the shadow is essentially like below it. And they kinda had a hard time with that, and they also had a hard time with perceptions as far as, you know, sun changing position. They realized that it moved, they didn't always know or necessarily understand how that affected the shadow to make it bigger or smaller… so they were aware that the sun moved and they were aware of the shadows changing size, but they weren't aware of how those two concepts worked together to change the shadow so those were the two things that we tried to work on more. (I-1)

Reagan described that teaching about light and shadows involved taking students outside and using two different sized objects to observe shadows, as well as using a flashlight and shining the light at different angles and observing the resulting shadows. In addition to Reagan's description of her lesson, we examined the lesson plan she developed about light and shadows. Her lesson plan was built around a specific objective: "Students will investigate shadows indoors and outside to develop their understanding of the sun as a light source and how it's [sic] apparent motion across the sky changes the size and direction of the shadows formed" [lesson plan]. She introduced the lesson by asking targeted questions about shadows. In terms of the activity, Reagan provided students with materials (e.g., flashlights, opaque objects) to investigate shadows and guided them to think specifically about the relationship between the light source (including the angle at which this light source hits an object), the object, and the shadow. With respect to gaining perspective on Reagan's approach to teaching and learning, the examples above indicate that while she encouraged activity and exploration she attended to how students made sense of the ideas and how to structure learning experiences in ways that encouraged students to attend to salient features of a phenomenon.

Angela Like Reagan, Angela noted that though her academic struggles began early she valued what those experiences have helped her accomplish: "School never came easy to me so I had to learn how to study at a young age, kind of understand the process of education and applying yourself even at 7 years old" (I-1). Angela mentioned developing learning strategies as early as elementary school, and she easily related how her own learning struggles influenced her views of how students learn:

> Not giving the child the strategy for solving but leaving it open for them to discover for themselves, because I think that's the problem with education. We give too many answers and tell them this is the way it's done, we don't let them figure it out for themselves and make the connections that last a lifetime. Because when you figure out something for yourself you remember that forever, but if someone tells you something, five minutes later you may forget. (I-1)

Additional insight into Angela's idea of learning comes from an example she gave about what she would like students to learn in mathematics. She said she wanted students to:

> … solve [an equation] using their own methods and their own understanding, so for addition or subtraction the child may not line it up vertically and you know have place value and bar and place value and move it over, that's not meaningful for the child, but if they can sit there and break a number down and do it in a creative way that is meaningful to them and they can understand it and explain it to me…they have actually formed their understanding, it's meaningful and they will be able to pull from that for the future, not so much I have to line it up and I have to borrow from the next place value because the child is just knowing the steps, they don't understand why borrowing from the next place value you get ten. (I-1)

The excerpt above indicates that Angela was concerned that students go beyond knowing the procedures used to solve a math problem; she perhaps recognized limitations associated with knowing only the steps to solve a problem. Angela recognized that this process of coming to understanding is important in learning science, and this recognition influenced her view of her role as a teacher. She indicated a need to portray to students that she did not have all the answers because she felt this was a key to getting students engaged in learning science:

> The type of science learner I am as a teacher will reflect upon my students, so I must be the science learner I want my students to become…I will let my students see I do not know all and will never know all. I question how and why things work just as they do. (RR-3)

Angela viewed learning as a process, and she wanted students to understand that she was still involved in this process, even as a teacher.

Angela's views of learning as a process were consistent with her learning goals for her students. When Angela discussed the learning goals she held for her students in mathematics (see above quote) and science (example following), she discussed wanting them to understand complex concepts in meaningful ways. She recognized the role of the teacher was central in helping to facilitate the learning of these concepts through hands-on activities. In "trying to understand how the child thinks about it and work from there…[I] take the child's understanding and their thoughts and move into a way to maybe direct their thoughts, in a more concise, better organized way" (I-2). Angela recognized that she needed to monitor her students' thinking in order to help them learn complex science topics.

Angela's views of learning were reflected in the way she discussed planning for science instruction. In a lesson in which she engaged students in learning about why and how seasons occur in the southeast United States, Angela noticed that her set-up of the lesson had a significant impact on the ways in which her students thought about the seasons. Angela used a hands-on activity in which students used globes and flashlights to mimic seasonal changes. Angela was the only one of the four participants who mentioned modifying her activity in order to help students develop clearer pictures of the science concept she was trying to help them learn. When asked about how she might modify the lesson if she were to teach it in the future, Angela noted that the children had difficulty holding the axis of the earth steady as they rotated it around the sun in their classroom models. She noted how this made their process of coming to understand the model more difficult. By changing the model of the earth to have a constant axis tilt so that the students would not have to keep it steady themselves:

> It's going to make the demonstration clearer…if the demonstration's clearer then they're able to form, you know, more accurate ideas as to why this is really happening as opposed to, when the activity is done incorrectly, they're forming incorrect ideas and becoming frustrated. (I-2)

Angela also mentioned other ways that she could help students form correct ideas about the seasons. She said that she would use:

> Another visual component that would help explain it better as opposed to just the hands-on 'cause some of the students really understood it and were able to manipulate it correctly, whereas others were really confused with what they were doing because they…didn't remember, okay, I have to keep [the axis] fixed. (I-2)

This role of a teacher in helping students to come to correct ideas about science concepts was something Angela took seriously, but she understood the difficulties associated with teaching science through hands-on activities and helping students construct correct and meaningful understandings of scientific concepts. Angela recognized that in order for students to develop correct understandings of science concepts, her role as a teacher required her to structure hands-on learning experiences and guide student thinking about science phenomena. Therefore, while Angela used language often associated with discovery learning experiences, the ways in which she structured learning experiences for students and talked about monitoring student ideas were more consistent with dialogic learning than discovery learning.

Summary Both Reagan and Angela gained knowledge about themselves as learners by reflecting on their own learning struggles. In both cases there were apparent connections between their own struggles with learning and their views of teaching. Both described learning as a process, and both indicated that the learning process is facilitated by the teacher but must actively involve the students. They talked about how struggling to come to an understanding, though oftentimes frustrating, helped them become better learners. These experiences as struggling students taking responsibility for their learning helped Reagan and Angela plan learning experiences containing hands-on activities that involved their students in coming to meaningful understandings of science concepts. Further, Reagan and Angela recognized the benefit of struggling in coming to understand science concepts and, particularly in the case of Angela, recognized how to support students' meaning making, as evidenced by her discussion of how she would modify her lesson.

We argue that Frykholm's (2004) notion of educative discomfort is useful for understanding how Reagan and Angela used their own experiences as struggling science learners to think about learning and teaching in a way that matches the constructivist ideologies of current reform efforts. Both Angela and Reagan mentioned explicitly that they struggled academically in elementary school and that, though those experiences were uncomfortable, they helped them to develop their own learning strategies in order to be successful in school. They were able to use their experiences of struggling in learning and subsequent successes as "good" students as a resource for thinking about struggling with the planning of science experiences for their students. Their experiences as struggling learners were *educative* in the sense that they prepared them to feel more tolerant of the discomfort they experienced as facilitators of developing meaningful understandings in their students.

Cases of Debilitating Discomfort

Frykholm (2004) described reasons for why teachers may experience debilitating discomfort, ranging from discomfort with the depth of their own content knowledge to discomfort with their own ideas about teaching and learning that content. We found that both Analeigh and Sharon avoided struggle in their own science learning experiences due to their discomfort with their knowledge of science. In addition, this avoidance of struggling with science concepts was preventing them from allowing for students to actively construct ideas in the science learning experiences they planned.

Analeigh Like Regan and Angela, Analeigh mentioned that science was not her favorite subject. In order to gain admittance into the early childhood education program, undergraduates were required to take four science content courses. Analeigh described how she chose those courses:

> [science] has never been my favorite subject and it's never been really emphasized too much throughout my years especially once I came to college, 'cause they were like you have to take 4 science classes to get into the major but they can be anything… I don't really like science that much so I'm going to take the easiest ones I can find. (I-1)

When asked which science class she liked the most, she said she liked her entomology class because the professor "put notes up on the board that we could clearly copy and this was on the test this was, it was very clear cut" (I-1). Analeigh's own learning experiences of science seemed to be an avoidance of struggle.

Analeigh's views of learning, however, were not wholly consistent with her learning experiences as a student. When she described meaningful science learning, Analeigh said: "I feel like learning science is doing science" (I-1) and "I want [students] to just have fun… I don't want to just stand up there and have them read a chapter from the book 'cause science is definitely a hands-on subject" (I-1). These views of learning science were consistent with the ways in which we talked about science teaching in the elementary science methods course. When we interviewed Analeigh after field experience, her views of learning were less clear: “I don’t think teaching from the textbook is necessarily a bad thing…I think it’s important to use the book because I think it definitely has good information” (I-2). This statement was not surprising given that Analeigh’s mentor teacher used the textbook as the central foundation for science instruction. When asked about why she planned hands-on activities for her students, however, she said:

> I think for most kids if they do something hands-on then they can remember it better because…it’s easier to remember something, the activity or experiment you did rather than when you were sitting at your desk reading a textbook, it’s easier to remember the activity. (I-2)

Though Analeigh seemed to contradict herself when she described methods for teaching science (i.e. whether or not to put the textbook at the center of learning), the view of learning described in the quotes above is the same: You have learned something when you can remember it.

Analeigh’s views on learning were reflected in how she planned her science lessons and in her reflections on the implementation of her lessons. When planning, Analeigh organized a unit on simple machines by introducing the topic using a storybook, teaching the information, and then reinforcing the information with a hands-on activity. This fit with her consistently fact-based learning goals for her science lessons and the way in which her mentor teacher structured her own lessons in the classroom (minus the hands-on activities). When she was asked to evaluate how she thought that her unit went, she talked about the impact on students in terms of what they remembered. “I definitely think they learned a lot because they were able to identify all kinds of simple machines” (I-2) and “I could tell they [the students] were having fun when they were doing it and I think they definitely got stuff out of it ‘cause in my writers’ workshop a lot of them started writing about…stuff that I had done in my unit” (I-2). Therefore, her evaluation of the unit was whether or not they remembered it and whether or not they had fun. This focus on the children having fun was important to Analeigh. When we asked her how she thought that learning math and learning science were similar, she said:

> I definitely think science is one of the most hands-on interactive subjects and so I think it definitely is good to have it…because it’s kind of a break up of the day, it’s fun, and there’s so many cool things that kids can learn, with science…it’s different every time, it’s not just like math, where you’re working through problems. (I-2)

Analeigh viewed science as a chance for kids to have fun and get involved in an activity; students were not necessarily involved in learning by thinking through concepts. Analeigh used language associated with reform-based science, but her ideas of practice mirrored the ways in which she felt comfortable learning and being taught (i.e., memorization). Her own learning experiences were about avoiding struggle, and the learning experiences she planned for her students did not give them a chance to work through concepts in a meaningful way. Therefore, her own learning experiences were debilitating when she tried to implement reform-based practices.

Sharon When Sharon discussed her experiences learning science, she mentioned being bored because she did not understand what was going on, she only tried to memorize things, and that her family rationalized that it was hard for her to learn science because she was a girl. She wrote:

> I was generally a ‘good’ student…but I never truly liked learning about science…In science, I only tried to memorize the facts because my teachers placed such a huge emphasis on test grades. I never understood how and why things happened, and teachers never made it a priority to teach me. (RR-1)

Her struggles in learning were seen by herself and her family as someone else's responsibility. Sharon's way of dealing with the struggle was to memorize and get through it. Because of these bad experiences in science, Sharon wrote: "I never thought that [science] could relate to me personally" (RR-1). These experiences made her nervous about teaching science because she was not comfortable with science based on her previous experiences as a science learner.

Sharon's learning struggles in science caused her to focus on encouraging student interest in science. She wanted to be the supportive, enthusiastic teacher she felt she missed as an elementary student.

> I did experiments in school but that, didn't really do anything for me because if I don't understand why something is going on, like all the terminology confused me, so I don't want to overwhelm kids with a bunch of terminology, I want to put it simpler so that they understand it, I want to make sure that my kids like it and that they enjoy it and that they're enthusiastic about it because I never was. (I-1)

Sharon intended to create a learning environment centered on students' interests. She was very focused on having student discussions be an integral part of her lessons because she believed this would allow students to enjoy science.

I think that's so cool, to let kids just be able to ask questions and ask questions, I know for me I'm never going to know all of the answers cause me and science don't really get along, but I feel like if they ask me a lot of questions we can all research together (I-1). She wanted her students to be actively involved in class and to participate in discussions and in hands-on activities. Yet when asked why she thought hands-on activities benefited students, Sharon responded:

> I feel like it's so much easier for a child to use their hands to figure it out and see it rather than just write it down…it's always been like that, if you make me copy something from a board and write it down, I'll forget it in 10 min, but if I get to see it happen, I think I'll remember it a lot longer, and so that's why for me that's why I prefer to teach [that way]. (I-2)

Sharon equated learning with remembering, just as Analeigh did. Therefore, despite the fact that Sharon was so dedicated to increasing the interest and enjoyment in her students in learning science, she only equated learning science with remembering. Her view of learning reflected the type of learning that she experienced in science (i.e., memorization), which made her disinterested in science.

Her goals for her students in science were reflected in the way in which she planned science learning experiences. Sharon linked enjoyment of science to the success of her lessons. In teaching about fossils, Sharon used an excavation of chocolate chips out of a cookie as her central hands-on activity. When asked about why she chose that activity, Sharon responded:

> I just went online to see something that I could do that would get them using their hand…I wanted them to be doing something, not just writing, and…the chocolate chip thing was just really cool I thought and kids love to play with food. They remember that for some reason. (I-2)

In her description of the planning process we saw how focused Sharon was on keeping student interest, planning a fun lesson, and having the students remember the activity. When asked whether she thought the lesson was successful, Sharon's response again stressed the importance of the students having fun and how that would help them remember science topics.

> They got to do something fun in science…I think I saw one fun activity in science, and so I think that they remembered it more. I don't think that they would remember

> a lot of other things that they did, but…they even talked about it towards the end [of field experience] and so I think that they really enjoyed it and so they got something fun out of science rather than just writing. (I-2)

Sharon's goal as a teacher was to make students like science rather than engage them in the kind of instruction that would allow them to develop conceptual understandings. The learning experiences planned by Sharon were therefore more superficial in exposing students to concepts but not allowing for opportunities in which they might work towards developing foundational ideas.

Summary Analeigh and Sharon were more passive in describing their own learning experiences and struggles with science. Though Sharon and Analeigh discussed their struggles learning science, they, unlike Angela and Reagan, did not seem to take personal responsibility for their own learning. Instead of developing strategies to deal with their discomfort with science learning, both Analeigh and Sharon avoided struggling in their own learning. Analeigh admitted to taking the easy way out, while Sharon lamented that others were responsible for her learning and did not fulfill their duties. This avoidance of struggling with concepts on the way to understanding left them without productive ideas about how to tolerate and deal with feelings of discomfort while teaching. While focusing on making learning experiences fun for students was a way in which both Analeigh and Sharon dealt with their feelings of discomfort, this approach is arguably not helpful in facilitating science learning. While their professed ideas about learning were philosophically congruent with reform-based science instruction (e.g. having students use observations as evidence to support inferences or ask scientific questions and figure out ways to go about answering them), Analeigh and Sharon tended not to create learning experiences with conceptual understanding as learning goals. Therefore, their avoidance of struggling in their own learning had a profound, and *debilitating*, influence on their willingness to engage in facilitating and developing student understanding of science concepts.

Discussion

While all four PSETs described struggling with science learning, their struggles were not interpreted in similar ways. Angela and Reagan used their own learning struggles to become aware of how they learned and talked about their learning in ways that showed that they felt responsible for their own learning. In comparison, Analeigh and Sharon talked about getting through science by memorizing and seemed to place the responsibility for their own learning with their teachers. We think that this key difference in how the PSETs reflected on their own learning experiences in science illustrates the categories that Frykholm (2004) described: *educative* struggle *(discomfort)* and *debilitating* struggle *(discomfort)*. While Angela and Reagan used their science struggles as a resource in thinking about understanding and learning in ways that begin to reflect the goals of science education promoted in national documents, Analeigh and Sharon did not enact science learning experiences that involved elementary students in meaningful understanding. Angela and Reagan took personal responsibility to develop their own learning strategies when struggling academically. Angela noted that struggling with a subject will cause a student to turn away from that subject, however, her own learning struggles, like Reagan's struggles, encouraged her to be more reflective about how hands-on activities were engaging students and were related to the concepts students were learning. This pair of struggling, yet responsible learners were prepared to reflect on the learning environments they wanted to prepare for elementary students. Angela also was prepared to distinguish between unnecessary struggles, as evidenced by her recommended change for the seasons activity, and opportunities for students to engage in wrestling with science topics.

Analeigh and Sharon were the PSETs least likely to change their learning goals in the direction of conceptual understanding perhaps because they did not expect students to take any responsibility for their own learning. Analeigh and Sharon had a passive view of learning, as evidenced in their views of their own learning experiences. Their personal learning struggles were a result of their teachers, and their own successes were dependent on memorization, not conceptual understanding. Despite their enthusiasm for hands-on activities, the learning goals of the lessons prepared by Analeigh and Sharon still focused on the learning of facts. Their goal as teachers was to convert students to liking science, rather than requiring them to struggle or work towards understanding science concepts. Their learning environments may have focused on hands-on activities, however, these activities were merely fun experiences for students designed to promote student interest, rather than opportunities for students to develop scientific understanding. Reagan and Angela reflected on their experiences as struggling learners and developed strategies to deal with discomfort in learning. This approach was *educative* in terms of helping them think about how to facilitate learning and understanding when designing science learning experiences. In comparison, Analeigh and Sharon dealt with their own learning struggles by actively avoiding experiencing future learning struggles. Therefore, the ways in which the PSET's historically dealt with struggle in coming to understand something (i.e. persisting through to understanding vs. avoidance of struggle) were reflected in the way in which they engaged with their roles as teachers of science in the elementary school classroom.

Conclusions and Implications

As articulated at the outset of the paper, teachers are expected to orchestrate learning experiences, be responsive to students' ideas, and guide them to understand science. Mikeska, Anderson, and Schwarz (2009) outlined three issues facing teacher educators/ researchers. Mikeska et al. (2009) wrote that *engaging in science* has been seen by PSETs as keeping student interest in science activities, therefore fun has been the main focus. In an attempt to encourage PSETs to present science as more than a collection of facts, these teacher educators/researchers are attempting to move pre-service teachers more towards the development of inquiry practices by developing their knowledge of science, science practices, and the nature of science. Involving teachers in inquiry science lessons in order to develop scientific practices, therefore, is a way to involve them in *struggling* to understand science concepts in more productive ways and to encourage them to develop these same types of learning experiences with students in the future.

In addition, teachers may find themselves in situations in which they are uncertain about how to respond to or redirect students' thinking. These are instances in which teachers may struggle with students' ideas as well as their own, yet these instances of struggle can be productive in terms of helping people—both teachers and students— sort out ideas in ways that lead to understanding. Two of the PSETs described in this study—Angela and Reagan—were able to manage struggle, both in terms of their own learning and in terms of designing instruction that encouraged student thinking. One of the commonalities between Angela and Reagan was that both understood they had to learn how to organize their learning. Based on how they described their science instruction, it was apparent that they also tried to find ways to help their students organize their learning. An issue for teacher educators to consider, therefore, involves encouraging PSETs to recognize strengths and weaknesses in their own learning and helping them understand why being metacognitive is an asset for teaching.

PSETs, however, may also be struggling to understand a way of learning with which they are foreign. Spector and Strong (2001) found that elements of the culture of science as dictated by the *National Science Education Standards* (NRC 1996) clashed with aspects of the behaviors and beliefs of the traditionally-aged—compared to non-traditionally-aged—pre-service elementary teacher culture. They found that the traditionally-aged PSETs were used to a culture of school that did not include open exploration, individual curiosity, open skepticism, and peer evaluation of ideas, which are some key characteristics of science and inquiry learning. These PSETs were grade-driven but unwilling to risk failing by trying new ways of thinking and behaving in school. If pre-service teachers are comfortable with more passive ways of learning, wrestling or struggling with conceptual understanding may seem foreign, frustrating, and of no benefit. Further, the two PSETs who avoided struggle—Sharon and Analeigh—admitted not feeling confident with their own understandings of science. They also indicated they did not choose to take science classes that would challenge them. Teacher educators should consider consequences associated with not encouraging PSETs to take science courses that could help them develop a solid content foundation. The combination of perceived lack of science content knowledge and being uncomfortable participating in a dialogic learning environment may be significant contributing factors for beginning teachers like Analeigh and Sharon who rely on instructional approaches that do not have much conceptual depth.

For pre-service teachers like Analeigh and Sharon, how can science teacher educators help them to plan and implement conceptually-based learning goals? Our particularistic case study has shown that in one cohort of PSETs, there were many students who struggled in their own learning of science but dealt with their struggles in different ways. The ways in which these students dealt with their own learning struggles mirrored the ways in which they dealt with their struggles to become teachers of reform-based science instruction. Helping PSETs to deal with their feelings of discomfort with science content or ideas about the nature of science learning and teaching promoted by reform documents may be a key issue in developing their willingness to become facilitators of meaningful science learning. We suggest that science teacher educators help PSETs pay attention to their own learning strategies and thought processes as a foundation for becoming teachers who monitor the conceptual development of their students. In conjunction, science teacher educators can support the relevance of monitoring thinking by modeling their own thought processes during content teaching events and how this practice can encourage discussions that elicit student thinking and ideas and move towards a dialogic learning environment.

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