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ABSTRACT

This research is part of a systematic, longer-term effort to study changes in the conceptions and beliefs of prospective teachers while teaming to teach science in a preservice teacher education program. This paper focuses on the impact of a project to reframe the theoretical underpinnings and pedagogical practices in a portion of the secondary science teacher education program at Penn State University. Two goals of the project were to: (a) design an innovative university and school-based program that explicitly considered "learning to teach science" as a process of conceptual change; and (b) examine the ways in which teacher beliefs and conceptions about learning and teaching science changed during the first level course in science pedagogy. The ways in which the prospective science teachers came to make sense of teaching science for understanding and identify particular course events that stimulated this sense-making are examined. (Contains 42 references.) (ASK)

Creating Dissonance in Prospective Teachers' Conceptions of Teaching and Learning Science

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The research reported in this paper is part of a systematic, longer-term effort to study changes in conceptions and beliefs of prospective teachers while learning to teach science in a preservice teacher education program. Some of the reports of this line of research are included in this paper set while others can be found elsewhere (e.g., Bradford, 1997). Specifically, the impact of a project to reframe the theoretical underpinnings and pedagogical practices in a portion of the secondary science teacher education program at Penn State University is the focus of this paper. Two of the goals of the project were: (a) to design an innovative university and school-based program that explicitly considered "learning to teach science" as a process of conceptual change, and (b) to examine the ways in which teacher beliefs and conceptions about learning and teaching science changed during the first level course in science pedagogy. For the purposes of this study, conceptions and beliefs about "teaching science for student understanding" was isolated as a key idea for investigations since this idea appears centrally important to contemporary visions of science education reform (e.g., Mintzes, Wandersee, & Novak, 1998). Therefore, the purpose of this paper is to examine the ways in which the prospective science teachers came to make sense of teaching science for understanding, and to identify particular course events that stimulated this sense-making.

Conceptual Perspectives

The design of this research project and the course in which it is based comes about as a result of our exploration as science teacher educators into the teacher education implications of teaching science for understanding. First, we present an overview of the theoretical foundations of our work. Second, we describe the nature of an integrated methods/field course which seemed to facilitate prospective science teacher growth contingent with the philosophies guiding recent science education reform efforts.

Learning to Teach Science for Understanding

A constructivist view of learning was one of the guiding theoretical elements in this project (e.g., von Glasersfeld, 1989). This perspective on the learning to teach process has been explored in other teacher education research programs with encouraging results (1997; Hewson & Hewson, 1989; Simon & Schifter, 1991). A significant implication of thinking about constructivism in educating teachers is that science teachers should be conceptualized as inquirers into teaching and learning, rather than technicians who are hired to simply deliver a curriculum to children. Learning science teaching is a process of making sense of new ideas and experiences in teaching and learning, in light of what one already knows. The construction of new knowledge is strongly influenced by prior knowledge; that is, conceptions constructed prior to a new experience will influence the way that experience is perceived. From a constructivist perspective, teacher knowledge is not found in textbooks or external "science education experts;" rather, it is both personally created and socially mediated as prospective teachers of science make sense of their experiential worlds. It can be expected, therefore, that prospective teachers of science build conceptions about learning and teaching science that are based on their own past experiences with, and subsequent assumptions about, education.

In the case of prospective teachers of science, an extensive network of knowledge has already been constructed about what it means to teach science. Researchers who study the development of teachers of science recognize that conceptions of teaching science are generally based on the teachers' own experiences as learners of science in schools, as learners of science at the university, and as learners in formal courses and clinical experiences in the teacher education program (e.g., Britzman, 1991; Richardson, 1996; Weinstein, 1989). Hewson and Hewson (1989) indicate that in learning to teach science, prospective teachers construct a conception of teaching science that is comprised of cognitive structures about: 1) a rationale for teaching; 2) a view of knowledge, learning, and science; 3) the nature and extent of science content knowledge; and 4) pedagogical knowledge. These experiences become the foundation for an image of science classroom life which serves as a guide for determining appropriate teacher and student actions.

A contemporary perspective on learning to teach acknowledges that learning about teaching is a complex process and assumes that (a) understanding teachers' conceptions and beliefs of science teaching and learning must be central to teacher education efforts, (b) learning to teach is an active, constructive process, and (c) learning to teach occurs in situated contexts. Significant and possible tenacious conceptions which may or may not be reflective of reform ideals are constructed from "apprenticeship of observation" (Lortie, 1975) over the many years that prospective teachers have been students in educational systems. Borko and Putnam (1996) contend that "research on learning to teach shows that teachers' existing knowledge and beliefs are critical in shaping what and how they learn from teacher education experiences " (p. 674). It might also be noted that most prospective teachers tend to have an "unrealistic optimism" about their initial abilities as teachers. This may prevent them from being receptive to the efforts of teacher education programs that attempt to help them reconstruct their conceptions and beliefs into ones more supportive of teaching for understanding (Brookhart & Freeman, 1992).

Researchers, notably McDiarmid (1990), Ball (1988), Hollingsworth (1989), Bird (1991), and Comeaux (1992) found that teacher education courses can influence prospective teachers' knowledge and beliefs, although these influences are strongly connected to variations in prior knowledge and beliefs about learning. These reports suggest that changes in conceptions and beliefs of prospective teachers may take place when conceptual change is an explicit goal of courses in pedagogy. In particular, changes in conceptions and beliefs about children's learning appears to be greatly influenced by initial teaching experiences (Bullough, Knowles & Crow, 1989; Calderhead, 1988).

Field experiences might provide opportunities for prospective teachers to reinforce long-held images of teaching and learning that may not be particularly productive for a goal of teaching science for understanding (Mintzes, Wandersee, & Novak, 1998). It has been argued that field experiences have not been very powerful in assisting future teachers to question the assumptions and beliefs they have developed as a result of over 13 years of passive observations in school (Barnes, 1989; Feiman- Nemser & Buchmann, 1985; Britzman, 1991). What if, however, early field experiences were viewed by science teacher educators from the lens of a conceptual change approach?

A conceptual change approach to teacher education could enable a prospective teacher to

> ...recognize his/her conceptions, evaluate these conceptions, decide whether to reconstruct the conceptions, and, if they decide to reconstruct, to review and restructure other relevant aspects of their understanding in ways that lead to consistency. While these processes of recognize, evaluate, decide whether to reconstruct, and review other aspects of understanding are individual, each is profoundly influenced (positively or negatively) by the ways in which the teacher, and other class members, structure classroom practice. (Gunstone & Mitchell, 1998, p. 134).

The conceptions and beliefs about science teaching and learning that are held by prospective teachers play an important role in the learning to teach process. They serve as a filter for learning during teacher education and may need to be considered a programmatic target of change through some organized means. Conceptions and beliefs held about learners and learning are especially important to prospective teacher development in an age of reform. The task of designing opportunities to challenge prospective science teachers' existing beliefs and conceptions and to develop alternative conceptions that are more consistent with the constructivist, learner-centered approach currently espoused in our field (e.g., Mintzes, Wandersee and Novak, 1998) became a central goal for us as we attempted to reconceptualize our science teacher education endeavors at Penn State.

The Course

The challenge we set for ourselves was to design a set of guided experiences that would help prospective secondary school science teachers in an introductory course in science pedagogy to continuously and meaningfully examine their own implicit and explicit conceptions of science teaching and learning. We especially wanted to foster the prospective teachers' abilities to look deeply at student learning and to consider learners as active participants in the learning process. Simultaneously, we endeavored as instructors to do the same. We sought to develop structures in the methods course that would acknowledge and capitalize upon the prospective teachers' own process of conceptual change around the issue of teaching science for understanding.

We restructured the existing course in ways which encouraged the prospective teachers to identify and articulate their beliefs about science teaching and learning, to test those beliefs, to reflect upon their strengths and limitations, to consider other viable options, and to test and reflect upon those options. While some of the opportunities to test beliefs occurred in regular course activities at the university, it was agreed by the instructors that a teaching experience in local schools might help to focus the prospective teachers on student learning while provide the type of feedback often valued most highly by prospective teachers--student reaction to teaching practice. The integrated methods-field course offered the prospective teachers opportunities to: plan a lesson explicitly based on their own beliefs about good science teaching, teach the lesson to high school students, assess the students' understanding, and reflect on the implications of those data for teaching. The initial plan-teach-assess-reflect sequence occurred in the first few weeks of the course. The middle of the semester was dedicated to the re-examination of beliefs about how best to teach science for understanding, as well as opportunities for the consideration of pedagogies that could further this goal. Near the end of the course, the prospective teachers revised their initial lesson plans, taught the lesson to their peers, and then participated in a second sequence of the plan-teach-assess-reflect cycle with a new group of high school learners.

Hewson (1996) indicated that a key factor in learning is the notion of "status." The conceptual change model suggests that changes in conceptions do "not occur without concomitant changes in relative status of [those] changing conceptions" (p. 132). Consistent with models of conceptual change (Hewson, 1996; Posner, Strike, Hewson & Gertog, 1982), we expected that the prospective teachers' original beliefs and conceptions of exemplary science teaching and learning would be perturbed and called into question, their status lowered, if the high school students did not gain understandings from the lessons that were as deep as the prospective teachers anticipated.

Although we did hope that those prospective teachers who were not treating the learners as active participants in the learning process would be able to see the limits of their approach, we did not wish to purposefully create such a discrepancy that a particular prospective teacher might be overly distressed or react defensively. In order to build developmental support for the prospective teachers, many of whom had not previously taught, the field experience was carefully structured and monitored by both the methods instructors and the cooperating teachers from the high school. Together, we attempted to create a space in which the prospective teachers could, with minimal risk, experiment with teaching and concentrate on examining student learning. We hoped to lessen classroom management concerns, thereby allowing the prospective teachers to concentrate more fully on the learning process of their students, by restricting the teaching to small groups of students. Two or three prospective teachers shared the space available in a given classroom: student groups were rotated for the second teaching experience so that the prospective teachers would also be able to examine the impact of their revised lessons. A methods instructor was on-hand in classrooms during the teaching episodes, but not as an evaluator of teaching performance. At the beginning of the semester, the prospective teachers had been told that they were expected to be professional in terms of planning, appearance, and manner; but that the teaching experience itself was their time to "try things out," and would remain ungraded.

Lessons were to last 30 minutes, with another 10 minutes for an end-of-lesson assessment of student understandings. Additional data about student understandings were gathered through student journal entries assigned by the cooperating teachers on the day following the lesson. Further, the cooperating teachers agreed to have the prospective teachers return to their classrooms a few days later, so that they could pull students out for conceptual interviews that more deeply probed the limits of the content understandings that the students had derived from the lessons. All of the assessment instruments, like the lessons themselves, had been developed by the prospective teachers. They were given extensive guidance in the creation of the assessment instruments, as well as the rubrics that would help them to interpret their data, during the first few weeks of the methods class. Only limited comments, however, were offered on the lesson plans. We attempted to ensure that none of the prospective teachers would have either a completely miserable or an unsafe teaching experience with the high school students, but crafted our comments carefully so that the prospective teachers did not get feedback that overrode their own conceptions of what or how to teach students. If the lessons were not felt by the prospective teachers to be a product of their own beliefs about teaching and learning, then the results of those lessons would neither have been meaningful for the prospective teachers, nor would it have had the potential to precipitate conceptual change.

Methods of Research

Design and Procedures

As the major objective of this study was to examine changes in prospective science teachers' conceptions of teaching and learning science over the duration of a methods course, multiple data sources were employed to capture dimensions of their conceptions of science teaching and learning. Our focus was to examine and understand those conceptions, with particular attention to the ways in which the prospective teachers were making sense of the idea of teaching for conceptual understanding. To that end, course assignments had been purposefully designed that would help the prospective teachers reflect on their own beliefs, and, eventually, about the means and ends appropriate for teaching science for understanding.

Activities and assignments for the course were often open-ended, so that the meanings that the participants themselves assigned to issues and events would emerge. Main data sources included: pre- and post-course concept maps of "science teaching and learning," written statements of the prospective teachers' philosophies of education, multiple drafts of lesson and assessment plans (with pre-teaching rationales for both content and pedagogy selection), post-teaching self-analyses, reflective journals, videotapes of methods course activities and discussions, anonymous mid-term and final course evaluations, and a modification of the Conceptions of Teaching Science instrument (CTS) developed by Hewson and Hewson (1989). The CTS was designed to examine teachers' conceptions of science teaching by asking them to choose instructional strategies in response to an imagined science teaching episode in which the student learning that occurred did not match the expectations of the teacher. We modified the instrument so that the prospective teachers were asked to respond to their actual first teaching episode in the field and to the data they had collected from their students. They were to consider the strategies that they might employ if they were to teach a follow-up lesson the next day, and to explain why they would consider each instructional option very important, somewhat important, or not important to them as teachers. Ten options were given, each approximating different degrees of teacher- or learner-centeredness. Additionally, a space was provided in which they could create their own instructional option. The triangulation of emergent themes across all of the data sources helped to enhance the credibility of assertions (Lincoln & Guba, 1985).

Inductive analysis was used to reveal themes in the data set (Bogdan & Biklen, 1992; Merriam, 1988). Text analysis was used in order to represent the participants' thoughts and ideas as faithfully as possible. All sources of data were repeatedly examined to allow emergent patterns to surface (Lincoln & Guba, 1985). Multiple readings through the data enabled the researchers to construct themes from the participants' words, which were recorded in margin notations (Miles & Huberman, 1994; Strauss & Corbin, 1990). The data were then examined more closely, to see how well they fit the "emergent theme, configuration, or explanation" (Miles & Huberman, 1994, p. 69). Developing assertions were tested by seeking both confirming and disconfirming evidence (Patton, 1990). The instructors worked independently first, then collaboratively, to triangulate emerging themes and concerns (Patton, 1990). Differences in the understandings of the researchers were resolved through negotiation until a point of acceptable consensus was reached.

Of the twelve prospective secondary science teachers in the course, seven were female and five were male. Three of the future teachers were prospective physics educators, two were studying earth science, and seven were studying biology. All but two of the students were traditional undergraduates.

Creating Dissonance by Challenging Beliefs

The teaching and learning course was purposefully designed to support the prospective teachers' conceptual development around ideas connected to teaching science for understanding. Certain aspects of the course appeared to be especially helpful in creating dissonance, challenging beliefs, and fostering the reconstruction of science pedagogies, stimulating the professional growth that was the focus of this study.

The course elements that appeared to have greatest impact on the prospective teachers were those which offered ongoing opportunities for the articulation and testing of their conceptions about science teaching and learning, as well as the elements which provided models of teaching for understanding. The prospective teachers were continuously asked to make explicit their thinking about science teaching and learning through course activities like concept mapping, focused journal writing, and guided class discussions. The two plan-teach-assess-reflect cycles were very powerful course events, especially since they were based in the schools and therefore demonstrated "real results" via their access to actual high school students. The three other course events that were mentioned repeatedly as potent catalysts for learning about teaching for understanding were lessons modeled by course instructors, video clips from the Private Universe Project (1995), and particular course readings. The assertions presented in this section have been inductively derived in an attempt to capture the connections between our conceptual change orientation to teaching teachers, the events of the methods course, and the changes in thinking reported by the participants in our study.

Teaching Science for Understanding Requires Transformation of Conceptions and Beliefs.

The prospective teachers developed their initial lesson plans based on their own ideas about what content and pedagogy was appropriate, with only minor guidance from the classroom teachers and university instructors. These initial teaching plans were viewed as a manifestation of pre-course conceptions and beliefs about science teaching and learning. When combined with reflective journal prompts and the prospective science teachers' involvement in other methods class activities and discussions, they allowed us insight into the prospective teachers' conceptions of appropriate pedagogy.

Even as juniors and seniors in a typical undergraduate teacher preparation program, the majority of participants already manifested what Anderson & Smith (1985) refer to as strong "orientations toward science teaching and learning." It is significant, but probably not surprising, to note that in each of these cases, the participants' initial orientations toward science teaching and learning could be described as content-focused and teacher-centered. Grossman (1990) contends that many teachers enter teaching without strong guidelines for appropriate content. Borko, Livingston, McCaleb and Mauro (1988) also found that beginning student teachers typically plan to teach too much content. In post lesson reflections, the student teachers in their study attributed the over-abundance of content in their planning to a lack of personal understanding of their learners. As the student teachers learned more about students and the students' understandings, their selection of content and pace of instruction became more appropriate.

The content-focused and teacher-centered conceptions of the prospective teachers in the present study served as filters for instructional decisions such as choice and extent of content objectives or pedagogy and the development of instructional sequences. After the first teaching and assessment episode, the prospective teachers analyzed the impact of their lessons. Amy, who taught a lesson on acids and bases, reacted to the student "boredom" she perceived due to her fast-paced presentation of the facts. "I had so much to cover and I was afraid I was going to run out of time" (Amy, Reflective Journal). Whereas she had initially characterized her lesson as "interesting because of the connections to everyday life," she now stated that, from the students' point of view, the time it took for her to present all of the many details about pH that she had wanted them to know was problematic.

Another prospective teacher, Brian, prepared a lesson about radioactive decay, including nature of radioactivity and half-life calculations. He realized during his lesson that students were generally familiar with the term radioactive but they had large gaps in their content connections and also held some serious misconceptions about what happens during decay. Brian had expected students to "have a myriad of responses" to the request he used to open his first lesson, "Tell me what you know about radioactivity." He was surprised when he received no responses. He rephrased the request, adding terms like "half-life" and "isotope" as he groped for any prompt that would result in a student response. The responses were shallow and lacking the detail he assumed the students would provide. Brian quickly concluded, based on his "entire forty-five seconds of teaching experience" that he had misjudged the prior knowledge of his student group and that the lesson he had planned with deep and extensive content could never be successful. Although concerned that he was deviating from his plan, he offered a lesson on the basic structure of radioactive elements and what happens to them at the atomic level during decay.

After the multiple assessments of the students (and most especially, the conceptual interviews) were completed, Brian was shocked to discover that his students thought that the process of decay was equivalent to disintegration. Their idea was that as radioactive decay progressed, less and less of the mass of the substance remained, until the entire substance actually disappeared. Perplexed by the realization but committed to deal with the situation, Brian focused his second lesson solely on decay and developed multiple representations of decay to assist students in developing an appropriate understanding of this idea. Brian learned some important lessons that had not been part of his original set of conceptions about science teaching and learning: that teachers need to examine students' ideas before they teach and plan content accordingly, and that teachers should continue to assess students' ideas in the service of instruction both during and after a lesson.

Deciding how to best design and guide classroom learning experiences so that all children learn science with understanding is a great challenge, even for the most distinguished science teacher. For the prospective teachers in the study, it was a challenge for which they had only a very limited knowledge base, and even a smaller experience base. In attempting to understand the factors that impact teachers' ideas about teaching, a growing research base clearly supports the notion that science teachers' conceptions and beliefs about science teaching play a pivotal role in their abilities to enact reform oriented science pedagogy (e.g., Briscoe, 1991; Carlsen, 1991; Hashweh, 1996; Smith & Neale 1989). Krajcik, Layman, Starr, and Magnusson (1991) contend that knowledge of specific instructional strategies and ways of representing key ideas is centrally important to teaching science for understanding. Similarly, Smith and Neale (1989) suggest that teachers' knowledge and skill of strategies such as "eliciting students' preconceptions," "presenting discrepant events," and understanding alternative explanations for scientific ideas seemed to make a difference in the teachers' abilities to enact a conceptual change pedagogy with a focus on student understanding.

While the dissonance created by their interactions with learners was important, it alone did not suffice in helping the prospective teachers to grow. Comments made throughout the data set reflected the importance of the mid-semester's activities.

> It was amazing to me, that even after my $100,000 education as a science major, that I would hold such a major misconception about something in my own discipline area. If it hadn't been for the seasons lesson, I never would have known. (Neil, Reflective Journal)

> The lessons that [the instructors] gave on the reasons for seasons both helped me realize how important it is that lessons are student-centered. When students can discover things and figure out concepts on their own, there is less misunderstanding. The students will learn more in a student-centered lesson. (Jarrod, Final Reflection Paper)

Once the need to know was created, it had to be fostered by learning about and developing the skills that would help the prospective teachers to be more effective.

> I was having trouble making my lesson more learner-centered and the activities mid-semester gave me more ideas. The [Project Universe] video, especially, was good. . .it contrasted multiple strategies. The "reasons for seasons" lesson you taught was very effective in showing how much difference in student understanding can result from the two different ways of teaching. (Anonymous Student, Final Course Evaluation)

Before the modeling provided by the teaching, videos, and readings, most of the prospective teachers had seemed bewildered and frustrated by their lack of knowledge of how to implement lessons that promoted deeper understandings.

It was interesting to us that even Jon and Sue, our two most inherently learner-centered prospective teachers, seemed to have gained so much through the teaching sequence and modeling activities. Analysis of Jon's initial data set, for instance, indicated that he held a view of science teaching and learning that was different from most of his peers. Whereas most of them seemed to embrace the teacher-as-teller role exclusively, Jon seemed to have broader ideas. His understanding of a science teacher's role incorporated an intuitive disposition toward classroom interaction and communication, as well as the provision of opportunities for student activity. We were impressed by Jon's abilities to see teaching as more than information dissemination or the simple provision of activity; however, he lacked an articulate rationale for the importance he attached to those pedagogies. By the end of the course, though, Jon wrote:

> To teach is not to inanimately read notes to a room full of expressionless faces but to engage in meaningful dialogue and experiences with students that promote authentic education of teacher and class alike. Teaching is a give-and-take situation. . . it is an active process in which ideas are shared, misconceptions are challenged, and pertinent questions and issues are discussed. The teacher must be observant and "tuned in" to the level of understanding of his or her students; if this level is lower than expected, true teaching occurs when adjustments are made. . .in order to improve these circumstances. (Jon, Final Reflection Paper)

Course activities helped him to organize his ideas about science teaching, especially teacher and learner roles, into a more coherent framework for promoting student understanding.

Similarly, other prospective teachers' frameworks seemed to contain much more interactive notions of content, pedagogy and assessment by the semester's end. In this excerpt, Jean demonstrates how an assessment event helped her to reshape the content and pedagogy on which her lesson was based.

> When asked to describe a food web, most of the students responded with food chains. They showed that some organisms were able to partake of organisms in other food chains--their explanation for showing how the organisms were interconnected. . .although they recognized that many organisms in the food web were interrelated, they were focusing more on food chains than on the web. This explained why they were not able to associate the results of DDT and the ketone release into [Local] Creek with the significance of interdependence within the food web. In an attempt to avoid this in my second teaching experience, I obtained a brief pre-assessment from the students. From this, I was able to ascertain the knowledge and understanding each student had [of] the food web concept. As it turned out, [the students] also related the food web with food chains. Based on this I decided to present the food web concept as a whole and place less emphasis on the food chains. To accomplish this, I provided an opportunity for students to interact

> with the food web concept through the construction of a three-dimensional food web. (Jean, Final Reflection Paper)

As a consequence of the deeper insights that she constructed about her learners' understandings, Jean's basis for decision-making about her teaching was expanded. The course focus on teaching for understanding seemed to facilitate the prospective teachers' development of more robust frameworks for their thinking about science teaching and learning. Without the dissonance provided by confronting the limits of their own beliefs about science teaching and learning, and the subsequent observation and development of skills that supported the new ideas, these prospective teachers might not have come so far in learning to teach for understanding.

Examination of Learner Understanding Is a Powerful Motivator in Learning to Teach for Understanding.

In the case of each and every prospective teacher in the study, the driving motivation in learning to teach science for understanding came about as a result of a classroom problem that they had not anticipated: namely, children not learning what the prospective teachers thought was taught. As Neil, for example, reflected on the initial lesson he taught and the assessment data he collected at the conclusion of that lesson, he remarked:

> There seemed to be something missing from their answers. The students knew that minerals were used in their every day lives, and they also knew that minerals needed to be conserved, but a major connection was missing. They did not seem to make the realization that the minerals that are used in our every day lives are nonrenewable, difficult to find, and therefore must be conserved. Their answers reflected some of the information I presented, but lacked the general overlying concept I was hoping they would learn.

Neil was perturbed by his apparent limited impact on learning in his analysis of these end-of-the-lesson assessments. That perturbation was compounded when he conducted interviews with students from his class several days after the lesson. Areas of his lesson that he thought the students had mastered were now sources of concern for him:

> The follow-up interviews with students were filled with "primitive" responses. Examples were "minerals are solids" or "minerals are not alive." I guess one of the most difficult sections of my lesson for the students to grasp was mineral formation. By the time of the interview, students had no grasp of mineral formation. I thought they knew this! I guess I need to change some things in my lesson!

Neil immediately began to struggle with making a decision about the objectives of the next lesson. He decided that the section of his lesson on mineral formation would be eliminated to create more opportunity to focus on the notion of minerals as a nonrenewable resource.

Janet, a prospective biology teacher, also reacted strongly to the one-on-one interactions she has with students in an assessment task and, like Neil, forecasted changes in the scope of content in her next lesson rather quickly. She wrote in a reaction paper:

> The quiz I administered immediately after the first lesson had very good scores. At first I thought I did a great job. Then I went in for the post-lesson interviews. All of my students were thrown by the ideas of catalyst and enzymes...this showed me

> two important things. First, if I had never done the interviews I would have always thought my students understood nearly everything I taught. Second, I realized that I need to streamline the next lesson and remove tangential concepts like substrate and enzyme-substrate complex that apparently confused my students thinking..

All of other the prospective teachers also pointed to the perturbation they experienced upon learning of the limits of their students' understandings as a key motivation for change.

> The actual teaching of high school students was the best experience, rather than just peerteaching a lesson. It made it easier to actually determine how well real students understood a concept. The interviews with the students helped me to look at this even closer. (Anonymous Student, Mid-Term Evaluation)

> The interviews were probably the most useful for determining what the students learned from my lesson, and what concepts they did not comprehend. By asking the students questions at the interview, I found out that they did not understand the connection between testing the streams for pollution and ground water. From the information gathered, I decided to change my lesson to help the students understand the concepts of ground water. (Marie, Final Reflection Paper)

Without the conditions that allowed these prospective teachers to focus upon learners and learning, the opportunities to transform their teaching in ways that supported teaching for understanding might have been lost.

Children's understanding of a concept taught offers some powerful opportunities for reflection on beliefs connected to science teaching and learning. Ann reflected on her experience in the course:

> Everyone who read my first lesson plan thought that I was trying to cover way too much information. Yes, it was true that I was covering a lot, but I was planning on not going into very much detail about any one concept. Regarding the first lesson I taught, I question how appropriate the particular lesson on nuclear radiation was for a ninth grade earth science class. I felt like everything was over their heads. For the revised lesson I wanted to keep the topic because it is important for students to learn about nuclear radiation but I realized that I needed to stick to just a few main concepts and cover them more thoroughly. But that wasn't enough - I needed to learn to plan lessons more effectively. I now see the value in including more learner centered approaches. For example, I decided that I would start my revised lesson with finding out what ideas or thoughts or impressions they were carrying around in their heads about nuclear radiation. I didn't care if they thought "explosions" or "The Simpsons," I just wanted something from them to work with. Instead of <u>telling</u> them what radiation is, I created a reason for them to want to know more about it....I specifically changed by second lesson plan to <u>not</u> explain what radioactivity is until about halfway through the lesson after I have heard their ideas and I created a "need for them to know." The knowledge of the students was much more diverse in the follow-up interviews this time. I even noticed this change during the lesson. It was more or less the same content, but it wasn't over their heads.

Ann's experience with students' not learning all that she expected helped her to raise the question of appropriate content, too, just like several of the prospective teachers mentioned previously. A difference with Ann, however, is noted in the ways she thinks about the mediational role of the teacher. Her conception of a science teacher as one who selects content and imparts knowledge to students, seemed to take a shift toward a science teacher as an individual who is actively involved in crafting the learning environment. While this was still a limited understanding for Ann, in this expanded view, she has acknowledged the role of the learner in the teaching-learning process. She now believes that learners do not automatically learn when simply presented with new information: learner readiness must be created.

The perturbation that the prospective science teachers experienced when they realized that their students had not learned with understanding was a powerful motivator for their own conceptual change about science teaching and learning. However, the prospective teachers did not discard fully or completely replace their original conceptions. Rather, they seemed to weave in incremental, yet significant new elements into their emerging schema for teaching science for understanding.

The Prospective Science Teachers Seemed to Seek a Conceptual Comfort Zone with a Balance between Teacher-Centered and Learner-Centered Pedagogies

Transforming conceptions and beliefs about teaching science toward those supportive of teaching for understanding apparently takes much time and support. Even with those conditions, it would be unrealistic to expect that one short experience or semester of experiences might fully supplant the beliefs constructed over a lifetime. Ann reported in her final course paper, "I learned how to balance my need to get concepts across with students' need to be engaged in order to learn."

This shift in stance is hopeful, and apparently a necessary beginning to continued learning about teaching science for understanding, yet it is important to consider the shape that this shift seems to be taking. Ann needed to seek out a conceptual space where she felt comfortable. Her comfort zone continued to include her ideas about the science teacher as provider of information but supplemented it with her ideas about student engagement in learning science and creating "a need to know" on the part of the learners. She seemed to be selectively assimilating the aspects of new thinking that were easiest for her to accept in light of the evidence provided.

Some of the other prospective teachers also selectively reconstructed their conceptions of science teaching and learning without necessarily confronting some of the inconsistencies inherent in their own philosophies. For example, when considering the prospect of moderating a discussion that uses the students' incomplete or naive ideas as starting points, Jean states:

> This would be an approach that would work well in allowing the teacher to see the students' background knowledge. If this could be done, say, at the end of the class period prior to the actual presentation, the teacher could adjust the presentation--the materials and strategies--to the level of the class. In this way, the lesson would not be too basic, nor too advanced for that individual class. (Modified CTS)

Jean's idea is that student prior knowledge can be a helpful planning tool for the teacher, but that its use is divorced from engagement with the students themselves. The teacher, in Jean's sustained view, influences student learning by selecting the proper scope of content. Changes in her conceptions are connected to giving more attention to the learners, but in ways that are not interactive or "on-line" during teaching. Rather, the purpose was to justify the depth and breadth of content that would likely be appropriate in a lecture.

Many of the prospective teachers also seemed to retain some portion of their belief in science teachers as tellers:

> I think teacher summary is important. This would give me an opportunity to stress main points and retouch upon the things that I did not fully explain. (Amy, Modified CTS)

Amy demonstrates that she feels that student learning is still a direct product of teacher explanation. For Amy, teaching science involved providing information to the learners, summarizing "key points" and then offering remediation through additional explanation.

There was also an apparent, overriding belief that a foundation of knowledge is a necessary prerequisite for either discussion or student activity. Following her first teaching experience, for example, Allie noted:

> A [teacher moderated discussion] would be somewhat helpful, For the "more advanced" students, this is great. But the lower level students in my group really struggled with open-ended discovery questions. (Allie, Modified CTS)

In Allie's view, students needed to be provided with background information before discussion would be productive for learners. For other prospective teachers, students needed a set of foundational knowledge before they could engage in activity:

> Doing additional activities for discovery of the concepts is important, depending on what/how the activity is related to the topic...they must be strong on basics first, if they are "to discover" further. (Jean, Modified CTS)

From what many of the prospective teachers had written, it seemed clear that learner-centered strategies could be useful to teachers; but perhaps merely as reinforcements for other, more teacher-centered strategies. The purpose of discussion and activity, in their views, served to demonstrate or verify the information already presented or summarized by the teacher.

When attempting to help prospective teachers to reconcile dissonant new information with the stories and experiences of a lifetime, science teacher educators should perhaps expect a step-wise transformation, rather than a radical about face. Deeply-held, and hitherto unchallenged, beliefs are notoriously difficult to change (Pajares, 1992). Building spirally upon previous gains may be a useful conceptual model for thinking about the facilitation of change in beliefs.

In our research monitoring changes in conceptions and beliefs of prospective science teachers we have learned that dramatic paradigm shifts were rare, if indeed they occurred as such at all. Rather, we witnessed incremental changes in thinking about science teaching and learning, especially with regard to children's learning of science and teaching for student understanding.

Conclusions and Implications: Facilitating Prospective Science Teacher Learning Through Constructive Dissonance

How can prospective teachers be supported in learning to teach in ways that challenge constructively the beliefs that would conflict with current conceptions of appropriate practice? What science teacher education experiences seem to hold most value in promoting changes in prospective science teachers' conceptions and beliefs about learning science for understanding?

Our focus is on facilitating prospective science teachers' learning to teach in ways that supports teaching for rich student understandings. Research by Ball (1988; 1989) and McDiarmid (1990) in introductory courses on teaching and learning demonstrate that even early on in a teacher preparation program prospective teachers can change their ideas about subject matter and ways of teaching and representing that subject matter when the explicit focus of the course is on identifying, challenging, and reconstructing conceptions and beliefs of content and pedagogical content knowledge. However, we recognize that no single course or instructional sequence is a panacea for promoting teacher learning. As Ball (1991) and Simon (1995) conjecture, aspects of teacher preparation courses, even sequences of courses over multiple semesters, seem to make some difference but may be insufficient to facilitate the kinds of changes in conceptual understanding and beliefs structure in prospective teachers necessary to achieve the kinds of teaching for understanding compatible with reform ideals. It may be that to combat years of learning that reinforce the status quo, the slow accumulation and layering of reconstructive experiences over many other years will be required.

Learning to teach science for understanding is complex and is complicated by many personal (e.g., prospective science teachers' prior conceptions and beliefs about content, learners and pedagogy) and contextual factors (e.g., focus on production of teaching artifacts such as lesson plans during field experiences and non-supportive cooperating teachers and university supervisors). In the study reported in this paper we endeavored to design an introductory secondary science teacher education course that makes an initial impact on prospective science teachers' concepts and beliefs about a centrally important reform ideal: teaching for student understanding. The principles that guided our efforts included:

Σ Learning to teach science for student understanding is a process of conceptual change for prospective science teachers. Therefore, conceptual change pedagogy is a useful heuristic to guide university instructors in designing courses in learning to teach science.

Σ Prospective science teachers' prior understandings and beliefs about teaching, learning, learners and science content must be elicited early and often and used as a point of departure in our courses/programs. Science teacher educators must find ways to help prospective science teachers to make implicit beliefs and conceptions explicit, find inadequacy in beliefs and conceptions that do not support teaching for understanding, create opportunities to construct more powerful beliefs and conceptions, and find ways for prospective teachers to elaborate and extend emerging understandings so they can be meaningfully integrated into their conceptual framework for teaching science for understanding.

Σ Prospective teachers need sustained opportunities to explore and test their conceptions and beliefs about teaching for student understanding through a planned set of at-university and in-school experiences.

Σ Learning to teach science is a life-long endeavor for science teachers. Helping to develop the inquiring habits of mind for continued learning throughout one's career as a teacher of science is crucial.

This has been an exploratory examination of our conceptual framework for educating prospective science teachers--it is unrealistic to think that the complexity of changes in prospective science teachers' knowledge bases can be captured well in such a limited study. Longer term investigations utilizing data sources that probe deeply into conceptual and beliefs structures as well as classroom practice are necessary in order to lend credibility to the high levels of interpretation that are characteristic of research connected to changes in science teacher beliefs.

The principal lesson from our research, however, is that there is some value added to the learning to teach process by creating some disequilibrium along the way. While Hollingsworth (1989) suggests creating dissonance by placing preservice teachers in classrooms of teachers whose ideas about teaching and learning differ markedly from the preservice teacher or from the teacher education program, we feel that dissonance is useful only when accompanied by enabling conditions. These would include, but are not limited to: the articulation and consideration of one's own beliefs, guided and reconstructive reflection, a safe atmosphere for experimentation and inquiry, and appropriate timing for key developmental events. The activities in this reconstructed methods/field course helped to make the learning to teach process generative, rather than imitative for these prospective teachers. We hope we can find ways to continue to capitalize on this momentum.

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