Misconceptions about “misconceptions”: Preservice secondary science teachers’ views on the value and role of student ideas.

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ABSTRACT: There remains a lack of agreement in the field of science education as to whether student “misconceptions” ought to be considered obstacles or resources, and this has implications for the ways in which prospective teachers think about the value of their students’ ideas. This empirical study examines how fourteen preservice secondary science teachers in four different science teacher preparation programs interpreted the rationale for eliciting student ideas. The findings indicate that the preservice teachers in this study showed an increase in recognizing the importance of student ideas, yet not all took the same view of their role and value in teaching, which appeared to be closely connected to beliefs about how learning takes place. Five different orientations to student ideas are described in the findings. These include viewing student ideas as evidence of content coverage, as obstacles to understanding, as tools to prime students thinking, interest, and activity, as elements of a positive classroom environment, and as the raw material of learning. The findings suggest that science teacher educators help focus preservice teachers’ attention on student thinking, and help them learn to incorporate their students’ ideas into their instruction in ways that build upon those ideas.

Keywords: Science teacher education, misconceptions, secondary science, constructivism, conceptual change
Introduction

In the opening pages of his groundbreaking textbook on educational psychology, David Ausubel (1968) wrote, “If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly,” (p. vi). In the decades following Ausubel’s articulation of this principle, the implications of Piagetian ideas about individual conceptual change, Vygotskyian insights about the role of language in the acquisition of meanings and concepts, and the sociological view of knowledge construction emerging from studies of the history of science, continued to focus attention on the existing knowledge learners brought to learning tasks (Novak, 2002). By the late 20th century, the way was cleared for a view of science learning in classrooms that placed the prior knowledge of learners front and center in any effort to teach science (Bransford, Brown, & Cocking, 1999; Duit & Treagust, 2008; Posner, Strike, Hewson, & Gertzog, 1982).

An impressive array of research since that time up through the present has reaffirmed the importance of taking the existing ideas of students into account in teaching for understanding. As Anderson (2007) has noted, the quest to identify and explore student conceptions about every scientific phenomena imaginable has been one of the most prolific programs of research in science education. This research has been fueled by the recognition that teaching for conceptual change entails having students articulate and examine their conceptions about various phenomena connected to the scientific topic at hand (Hewson, Beeth, & Thorley, 1998). The historical view that student ideas
inconsistent with scientific ideas are “misconceptions” has gradually shifted to a recognition that, at least in the mind of the learner, these are conceptions in their own right, with plausibility and at least some explanatory power (National Research Council, Donovan, & Bransford, 2005; Smith, diSessa, & Roschelle, 1993). Whether they exist in the mind of the learner as fully articulated alternative frameworks or fragmented ideas based upon abstracted experiences (Chi, 2005), fostering conceptual change in the direction of accepted scientific ideas remains a key goal for science instruction.

The role that student conceptions play in science learning appears to have been widely recognized by science education researchers and practitioners alike. In fact, a good argument can be made that if any “signature pedagogy” (Shulman, 2005) exists in science teacher education, the elicitation of student ideas and identification of probable scientific misconceptions is at its center. Efforts to direct teachers’ attention to student thinking take place across the professional continuum, and may be aligned with related efforts to foster teacher learning about formative assessment. The National Science Teachers Association in the U.S. regularly publishes teacher materials designed to help K-12 science teachers assess their students’ existing conceptions and incorporate knowledge of them into planning lessons (e.g. Keeley, Eberle, & Farrin, 2005). A number of projects originating at the Harvard-Smithsonian Center for Astrophysics, such as the Private Universe and MOSART projects have similarly sought to situate learners’ ideas about scientific phenomena as central to the teaching and learning of science (Sadler, Coyle, Cook-Smith, & Miller, 2006; Schneps, 1997; Schneps, Sadler, & Harvard-Smithsonian Center for Astrophysics, 1987). Additionally, a comprehensive database of assessment items for identifying student preconceptions of science has recently been
established as part of Project 2061 for use by teachers and researchers (American Association for the Advancement of Science, 2011). Clearly, the first half of Ausubel’s suggestion to ascertain what learners already know is currently being acted upon by the science education community.

The second half of Ausubel’s principle has proven to be somewhat more problematic, at least in terms of acting on what students know. What exactly does it mean to “teach accordingly?” Once a teacher has ascertained students’ ideas, what is to be done with them? Certainly less consensus exists concerning these issues, which cover pedagogical, curricular, and even philosophical ground. The question of what it means to take into account the ideas of students in one’s teaching is a central theme of this article, and I do so by examining how this message is being interpreted by those learning to teach in middle and high school science classrooms. I seek to learn how preservice secondary science teachers perceive the value and role of student ideas in their teaching by examining the purposes they cite for eliciting student ideas as well as by exploring the intended uses to which these ideas are to be put in practice.

The specific research question I pose in this paper is: What conceptions do preservice secondary science teachers hold concerning what to do with their students’ ideas about science, and how do these conceptions change over the course of a year in a teacher education program? The answers to these questions ought to have significant implications for science teacher educators in how we frame the purposes of eliciting and acting upon student ideas for our prospective science teachers.

**Background**
Smith et al. (1993) depict learner misconceptions as “faulty extensions of productive prior knowledge,” (p. 152) and it is this characterization that will be adopted in the present work. The word “misconceptions” as used here serves as a useful linguistic and discursive marker for a wide range of terms, including alternative frameworks, preconceptions, prior knowledge, student ideas, conceptions, and a host of other cognitive labels among which it might be important to distinguish in a different context. However, given that the aim of this paper is to explore the different views that preservice teachers have about student thinking, these distinctions carry less weight here, and using the word “misconceptions” is an economical choice. I ask forbearance on the part of the reader for the casual and frequent use of such a problematic term in this work, and recognize the potential criticisms I invite in framing this study as an investigation of misconceptions about misconceptions.

Nearly twenty years ago, Smith et al. (1993) took issue the way that the literature on misconceptions had taken on features antithetical to the principles of constructivism, which they defined as a “process of learning as the gradual recrafting of existing knowledge that, despite many intermediate difficulties, is eventually successful.” In particular, they noted that the characterization of misconceptions as mistakes unnecessarily minimized the role that these ideas play in learning. They also strongly critiqued the view that misconceptions must be “confronted” and “replaced,” and claimed that the underlying theory of discontinuous knowledge development implied by such a position was untenable. Smith et al. also implicated some of the foundational literature in the field (Posner et al., 1982) in presenting conceptual change in this manner. From a constructivist perspective, they argued that learner misconceptions are a resource that can
be tapped into for instruction, rather than mistakes to be replaced, overcome, or confronted.

As a result of these and other theoretical critiques of misconceptions and conceptual change research (e.g. Pintrich, Marx, & Boyle, 1993; Sinatra, 2005; Strike & Posner, 1992) the field has responded by and large with a shift toward what Vosniadou & Verschaffel (2004, p. 447) term a cognitive-developmental approach, which they claim is consistent with affective processes and, “uses constructivism to explain students’ misconceptions and to provide a comprehensive framework for making meaningful and detailed predictions about the knowledge acquisition process,” (p. 447). Unfortunately (and perhaps with no small irony), misconceptions about misconceptions remain embedded in the science education and science teacher education literature, much of which continues to represent the view that misconceptions are mistakes and/or obstacles to be replaced, overcome, eliminated, and prevented. In this paper, I argue that the perspectives on misconceptions held by science teacher educators and science education researchers have a very real impact on what prospective teachers think about the pedagogical implications of their students’ ideas. Consequently, it is worth a brief detour into the literature to examine the discourse used by science education researchers to discuss the pedagogical implications of student misconceptions about scientific phenomena.

The Metaphors of Misconceptions

Looking at the language used by science education researchers during the past two decades, it appears that the critique by Smith et al. (1993) is still valid in many cases.
In a thorough review of research using keywords “science teacher education” and a wide variety of other terms such as “prior knowledge,” “conceptions,” etc., the majority of published peer-reviewed articles continued to refer to misconceptions as obstacles to learning. Notably fewer authors framed misconceptions as resources. It seems likely that the continued conflation of these two views in the literature is more a result of imprecise use of language rather than a genuine disagreement over the role of student ideas in teaching. Given that metaphors influence thinking in powerful ways (Lakoff & Johnson, 1980), casting misconceptions metaphorically as either obstacles or resources carries implications for how student ideas are intended to be incorporated into teaching practice. Therefore the explicit and implicit metaphors for the role of student ideas in science teaching will be addressed in the remainder of this work as they arise.

The following sections are meant more as an illustrative view of the categories of discourse about misconceptions in the science teacher education literature, rather than a comprehensive quantitative analysis of this discourse. The point is simply to show that the field of science teacher education is still strongly oriented towards a view of misconceptions as obstacles, at least as represented in the language used to discuss misconceptions in this literature. It remains a matter of conjecture as to whether this discourse is reflected widely in science teacher preparation programs, though such a claim would be given empirical support by the findings of this study, as will be shown below.

**Misconceptions as obstacles.** When student misconceptions are cast as obstacles, their presence implies a barrier to student learning, and suggests that their absence would lead students to more directly to the learning of the desired content. In science education
research that takes this view, misconceptions are considered to hinder learning by preventing access to central scientific ideas, blocking the ability of the student to understand concepts, and affecting how students acquire new knowledge. Two examples from the recent literature illustrate how this language can creep into the most well-intentioned constructivist approaches:

Clearly, alternative conceptions can interfere with learning, suggesting that instruction must be carefully designed to address preexisting ideas. (American Association for the Advancement of Science, 2011, p. 384)

Subsequent research programs have been quite successful, bringing to the fore alternative ideas students have (sometimes called “alternative conceptions,” “naïve frameworks,” or “misconceptions”) that can hinder the learning of accepted scientific notions. (Stewart, Cartier, & Passmore, 2005, p. 281)

From this perspective, the discourse surrounding the pedagogical implications of misconceptions as obstacles invokes similar language of dealing with impediments. The most vague and mild among these indicate a need to address or acknowledge misconceptions, while others suggest that misconceptions must be changed, replaced, avoided, and overcome. More forceful are recommendations to eliminate or extinguish students’ misconceptions. Indeed, Hammer (1996) even includes such language in a
definition of misconceptions: “[Misconceptions] must be overcome, avoided, or eliminated for students to achieve expert understanding,” (p. 99).

Treating misconceptions as obstacles can also open the door to viewing incorrect student ideas pathologically, as matters to be diagnosed and remedied. The description by Ekici, Ekici, and Aydin (2007) takes this form: “In this study…the usefulness of concept cartoons as an instructional tool and a teaching method in diagnosing and remedying misconceptions about photosynthesis has been examined” (p. 121). Other studies have employed similar language to describe student misconceptions with the "right” answers playing the role of the cure. The elicitation of ideas in this formulation serves the metaphorical function of detection, as in the following: “It is important to determine students’ alternative conceptions as well as their sources and develop suitable teaching strategies in order to remedy them” (Taştan, Yaşar, & Boz, 2008, p.444). The notion that schoolwork consists of a series of right answers (Willingham, 2009) may be common among students, but is less common in the misconceptions literature. Examples can be found however, and they fit within this view of remediation: “Each learning activity…was designed to correct a corresponding misconception,” (Liu, Lin, & Kinshuk, 2010, p. 185).

Of particular relevance here is the idea in the literature that misconceptions ought to be prevented, such as when Başer & Geban (2007) state that a goal of their study was, “facilitating meaningful learning and preventing misconceptions,” (p. 247). Though this view was far less common in the literature reviewed here, its use sometimes employed the pathological view of misconceptions noted above, and acting to prevent misconception formation took up the features of preventative medicine. For example,
Chang, Yeh, and Barufaldi (2010) raise concerns that multiple choice tests in science, such as those used by PISA and TIMMS, may have negative consequences in creating misconceptions:

Information retrieved by cues might provide an amplification effect similar to repeated practice, which reinforces relevant knowledge/memory stored in the brain, so that future recall becomes relatively effortless. In addition, multiple-choice tests consist of questions with several false statement choices and only one correct answer. In other words, the distractors in multiple-choice tests expose students to a considerable amount of incorrect information. Reading the choices might increase the student’s familiarity with the subject, but also cause them to misperceive erroneous information as correct, causing negative consequences later, especially among students who were less familiar with the subject area in the first place. (p. 279)

This is an intriguing finding, yet their choice of language describing the implications are startlingly clinical:

Neuroscience-related findings have supported that corrections made immediately followed by the test can reduce the formation of misconceptions, both in misconception disrupting and interrupting misconception formation…Consequently, immediately correcting false
impressions after a test likely would hinder the formation of
misconceptions in long-term memory, and help to construct a correct
cognitive structure. (p. 279)

The view of knowledge acquisition presented here allows for little to no agency on the
part of the learner, nor does it permit the possibility that the formation of misconceptions
may actually play an important part in the learning process. As will be shown below, for
some participants in the present study, this view of preventing student misconceptions
loomed large as a central purpose for eliciting student ideas in science teaching.

In fact, it may be the case that the widespread metaphor of misconception-as-
obstacle may be problematic in other ways. In a provocative study that examined how
misconceptions entered into student reasoning during the process of learning
electrochemistry, Hamza and Wickman (2007) questioned the premise that
“misconceptions automatically interfere with learning,” and noted that student
misconceptions, “may have a significantly less prominent role...when studied in relation
to all the contingencies of an ordinary learning situation,” (p. 160). In other words,
misconceptions need not interfere with learning.

To be clear, I do not take issue with the sentiment that it is more desirable for
students to hold ideas that are more consistent with generally accepted scientific
knowledge than not. It is certainly a better outcome if students learn the science content
their teachers are trying to teach them! My concern here is that the discourse of
misconceptions-as-obstacles has crowded out potentially more useful ways of talking
about student ideas that seek to leverage them as resources.
**Misconceptions as resources.** The depiction of student conceptions as obstacles to learning stands in stark contrast to the perspective that student ideas may serve as resources for the student or the teacher. This view draws upon a theoretical framework that broadens the definition of resources beyond conventional material resources to include personal, environmental, and social resources that are accessed during instruction (Cohen, Raudenbush, & Ball, 2003). From this perspective, the relationship between resources and learning is mediated by the way these resources are activated by both teachers and students.

As resources, student ideas are assets to be used to foster deeper and more meaningful learning. If they are used by the teacher in some fashion, they serve to guide instruction and pedagogy (Minstrell, 1982; Scott, Asoko, & Leach, 2007; Watson & Konicek, 1990). To teach explicitly for conceptual change, student conceptions that are both elicited and anticipated guide the teaching tasks and pedagogy of the classroom, and in this sense are closely tied with formative assessment (Black & Wiliam, 1998a, 1998b; Hewson et al., 1998).

Student ideas serve metacognitive roles as well, in the sense that students may explicitly compare their conceptions with other ideas when offering explanations, making arguments, and providing justifications (Beeth & Hewson, 1999; Hennessey, 2003; Thorley, 1990). These other ideas may originate with a teacher, fellow students, from written or electronic sources such as textbooks and websites, or they may be ideas suggested from the results of some empirical data. From this perspective, student ideas may be refined, revised, bridged, built upon, justified, compared, and evaluated. Much like any resource, they are used.
Preservice Secondary Science Teacher Views on Student Ideas/Misconceptions

In a study of four experienced secondary science teachers described as “exemplary” by district administrators, Morrison and Lederman (2003) found that participants felt that it was important to learn what students already knew prior to instruction. Yet none used any formal assessment tools to probe for student ideas, and found most student preconceptions unaddressed by instruction. Some teachers tended to “equate preconceptions with prior exposure to content in other classes,” (p.855) and all of them saw the existence of misconceptions after instruction as an indicator that reteaching was necessary. Noting that these findings indicated that non-exemplary teachers would be even less likely to diagnose student ideas, the authors concluded that preservice teacher education has a role to play in preparing teachers to elicit and work with student preconceptions.

Davis et al (2006) noted that preservice secondary science teachers “tend to focus on content and tend to sometimes view instruction as a transmission process.” Both de Jong et al. (1998) and Lemberger et al. (1999) pointed out the emphasis that secondary science student teachers placed on giving students correct or accurate information. Lemberger et al. (1999) also found that positivist conceptions of knowledge and transmissionist notions of teaching overwhelmingly framed conceptions about teaching for the preservice teachers in their study.

These studies and reviews raise the issue that despite preservice science teachers’ recognition of the importance of student ideas, they remain unsure of what to do with them or how to incorporate them into instruction (Davis et al., 2006; de Jong et al., 1998;
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Mellado, 1997). This was true even in a teacher education program that had a strong focus on teaching for conceptual change as part of its methods course (Hewson, Tabachnick, Zeichner, & Lemberger, 1999). Lemberger et al. (1999) offer the explanation that “from a positivist perspective in which the truth of scientific information is not at issue [the consideration of student ideas seems] irrelevant at best and counterproductive at worst,” (p. 378). Mellado (1997) noted that student teachers had various conceptions of what to do with student ideas that conflicted with science ideas. These conceptions included: seeing these conflicting ideas as mistakes to be corrected or eliminated, true alternative theories to be supported by the teacher, and wrong, but believing it would be wrong of the teacher to “tear them down.”

In a study that sought to examine the collaborative inquiry processes of novice secondary science teachers into their own practice, Windschitl, Thompson, and Braaten, (2011) tracked changes in participants’ views on the role of student ideas in planning instruction. In this project, the category of “Working with students’ ideas” was one of the four dimensions of their Model Based Inquiry instruction, and they developed a three-level rubric based on their empirical data to evaluate participants’ use of student ideas in their practice. The least sophisticated view they identified was labeled, “monitoring, checking, re-teaching ideas.” At this level they indicated that teachers began instruction without knowledge of student conceptions, and focused their instruction on ensuring that correct information was delivered to students. Checks for understanding took the form of whole class conversations, and teachers engaged in individual tutoring to assure that students learned what was covered. The next step up was termed “eliciting students’ initial
understandings,” and though teachers at this level elicited students’ existing questions, conceptual frameworks, or hypotheses about scientific phenomena, they did not consciously use this information to shape their instruction. The most sophisticated of the three levels of using student ideas was termed “references students’ ideas and adapts instruction,” and represented the broader goals of “ambitious pedagogy” envisioned by the project. At this level, teachers elicited their students’ ideas about science and used them to influence classroom conversations. They also engineered these conversations in productive ways that “reshaped students line of thinking across multiple lessons.”

Though this research sought to describe the extent to which preservice science teachers worked with student ideas, it was not designed to examine teacher thinking about other purposes to which their students’ ideas might be put.

In an earlier report on this research, (Thompson, Braaten, & Windschitl, 2009) these levels are represented as a potential learning progression (Duncan & Hmelo-Silver, 2009; National Research Council, 2007) for new science teachers in working with their students’ ideas. This idea will be explored further in the discussion section of this paper.

Levin, Hammer and Coffey (2009) noted that it is attention to student thinking in a broader sense—not just misconceptions—that ought to serve as the goal for preservice teacher education, and they document the experiences of a number of interns in their teacher education program who have been able to attend to student thinking in powerful ways. They also offered an explanation for why learning this process is difficult: “One major reason that novice teachers struggle to attend to student ideas and reasoning is their participation in the social and institutional systems of public schooling, which encourage framings of teaching in terms of classroom management and curricular coverage,” (p.
152). Lortie (1975) described this as the *apprenticeship of observation*, and it has been repeatedly identified as a major problem in learning to teach (Hammerness et al., 2005). Their solution is to reframe the substance of teacher education towards attending to student thinking. This suggestion will be revisited in the conclusion, after examining the preservice teachers’ orientations towards their student ideas, and how these changed (or did not change) over the course of a year in a teacher education program.

**Methods**

Fourteen preservice secondary science teachers in four different university-based teacher education programs participated in the full study upon which the present work is based. The primary focus of this larger study concerned how conceptions of teaching science in diverse classrooms changed over the course of learning to teach (Author, 2010). Over the course of one year in a teacher education program, qualitative and quantitative data were collected from preservice teachers through interviews and questionnaires (pre, mid, and post), teaching portfolios, written coursework and lesson-planning materials (shared via USB drives). At least one naturalistic observation of student teaching took place for each of the participants, though in some cases there were as many as six. A description of the questions and tools salient to the present study are described next, though the full instrument package and a description of its development from other teacher education research tools, in particular those developed as part of the Teacher Education and Learning to Teach (TELT) study (Kennedy, Ball, & McDiarmid, 1993; NCRTE, 1991) may be found in Author (2010). The demographics of the participants are shown in Table 1 below. A timeline for the data collection is shown in
Table 2, and includes descriptions of the corresponding coursework and fieldwork. Given space limitations, only the methods of teaching science coursework is shown in this table. All interviews were conducted by the author.

Hewson and Hewson (1989), describe a conception of teaching science as “the set of ideas, understandings, and interpretations of experience concerning the teacher and teaching, the nature and content of science and the learners and learning which the teacher uses in making decisions about teaching, both in planning and execution” (p. 194). To investigate the conceptions of teaching science held by teachers at various stages across the professional continuum, The Conceptions of Teaching Science interview protocols were developed for biology (Hewson, Tabachnick, Zeichner, Blomker, et al., 1999), chemistry (Hewson & Hewson, 1989), and physics (Hewson, personal communication, 22 October, 2007). This conception of teaching science may reasonably be considered a collection of interrelated theories about all of the aspects of teaching described above by Hewson and Hewson (1989). These theories hold explanatory and predictive power in the minds of individual teachers and help them to understand their experiences. In the present study, each prospective teacher’s “conception of teaching science” was constructed out of their responses to questions during the interview, though the focus of the analysis was primarily on the value and role of student ideas.
Many of the prompts in the protocols concern the ways in which teachers might respond to the ideas of students, and data collected in response to these questions illuminated prospective teacher thinking about student misconceptions. Additionally, two other subject-specific interview prompts provided useful data for the research question here. In the original TELT interview protocols, one question probed for responding to student difficulties with particular concepts, while another focused on novel student solutions to a problem. Both were quite productive in revealing how teachers might respond pedagogically to such ideas. For the purposes of the present study, these questions were adapted for biology, chemistry, and physics, and ultimately served as a robust source of information concerning what preservice teachers thought about what to do with student ideas. The biology versions of these questions are shown in Figure 1 below as an example. The interview data was the main source of evidence in this study, and data from the questionnaires, electronic portfolios, observation notes, and coursework served primarily to confirm or disconfirm tentative findings during the analysis.

[Insert Figure 1 about here]

**Data Analysis**

The Conceptions of Teaching Science interview protocols described above employ the analytic tool of précis statement construction as a way to synthesize large amounts of qualitative data into manageable units for further analysis (Hewson, Kerby, & Cook, 1995). While it is probable that some nuances in the data may be overlooked in
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This analytic approach, it has significant advantages in identifying and tracking changes in teacher thinking over time.

The first stage of analysis consisted of collecting evidence from each individual participant’s data set that pertained to their views on the value and role of student ideas in learning, and then constructing a three-part case summary in the following manner. Each of the interviews were imported electronically into NVIVO qualitative analysis software, and these data were initially coded to identify when study participants referenced student ideas, misconceptions, prior knowledge, etc. in any way. These statements were aggregated and further examined to determine what, if any, pedagogical purposes student ideas served in their teaching. The individual data sets were systematically searched for evidence that the described approaches were actually enacted in student teaching.

All of this evidence was compiled into a single case summary document for each individual. The first part of the case summary consisted of a précis statement that described the primary way in which student ideas were depicted in this evidence. Next, data for each individual was examined longitudinally to identify any changes in thinking about student ideas over the course of her/his teacher education program. A second précis statement was composed to describe these changes. A final summary statement for each case was then written as a result of this analysis in order to situate these changes within each participants’ teacher education experiences, with any longitudinal changes noted. Table 3 below presents an example of one such case summary.

[Insert Table 3 about here]
A cross-case comparison was then undertaken with these case summaries, and emerging themes were identified by looking across the individual cases. Once the themes emerged as a result of this analysis, the individual data files and case summaries were organized by theme, and reanalyzed for validity. Disconfirming evidence was sought for each category, and further refinement in the themes were made as a result. These checks also suggested the possibility that viewing these data through the lens of a learning progression might be beneficial. Seven of the fourteen cases were selected for “member-checking” (Gall, Gall, & Borg, 2003; Stake, 1995) the results with the participants. In the case of Roberta, this process confirmed her position as the sole member of a category.

I begin a discussion of the findings below with a brief description of the data from the broader study that led me to attend to the ways in which participants thought about the role and value of student ideas.

**Findings**

I wish to begin the presentation of findings by drawing attention to data from the original study that gave rise to the present investigation. Quantitative data collected from multiple administrations of the questionnaire instrument served an indicator function in this research, and was used to identify areas of teacher thinking that changed quantitatively (i.e. more than 2 points on a 7-point Likert scale), which could then be further probed by the researcher during interviews. Therefore, the interpretation of the quantitative data shown below is presented as a warrant supporting the qualitative findings, rather than as quantitative claims themselves.
A single item on the questionnaire initially prompted a closer analysis of preservice teacher thinking about student ideas. The item asked the prospective secondary science teachers to use a seven-point Likert scale to indicate the extent to which they agreed with the statement: “Teachers who offer clear explanations in class are able to correct student misconceptions about particular science topics.” On an instrument with over 100 items, this single prompt appeared to have some of the wildest swings over the first three administrations (before and after each participant’s first science methods course, and then after the first fieldwork experience). Indeed, the graph of the average response to this question in each administration, shown below in figure 2, is consistent with the findings reported below that participants generally gave greater weight to the value of their students ideas after taking a science methods course, but then retreated in this view following the completion of student teaching. While later analysis of individual changes offers a more nuanced view of how participants’ views changed (or didn’t change), the generalization that participants attended more to student thinking during their methods courses appears to hold for most in this study.

In all of the four science teacher education programs, significant time (2-3 class meetings of over two hours each) was devoted to the issue of student misconceptions in learning science, and each of the methods courses included a project in which preservice teachers were required to research and compile a detailed catalog of “misconceptions,” “alternative frameworks,” or “student preconceptions” about a given topic in science. All
participants showed evidence of increasing their understanding about the range of possible ideas held by students about particular topics, and most were able to describe the conceptual difficulties students might have with content in much greater detail at the end of their student teaching than they had at the beginning.

For example, when Fiona was asked at the beginning of her program if there are ideas that some students might have coming into a biology class that makes learning about plant respiration more difficult for them, she replied: “I don't know what would make it difficult for them. I think most kids know that [plants use] the carbon dioxide that we breathe out, that plants need water and they need sunlight and those are the main bases of plant respiration,” (Fiona interview, 12 June 2008). A year later, after completing the program, she had a much deeper understandings of what ideas her students might have: “They’re going to try to relate breathing in plants to breathing in humans…they’re going to be looking for lungs, [and] a nose, so how do they breathe? What about oxygen in their blood?” (Fiona interview, 10 June 2009).

The fourteen prospective teachers in this study also showed evidence of gaining a deeper understanding of what difficulties students might encounter in science learning, yet not all took the same view of student ideas, as will be shown below. Conceptions about the role of student ideas in learning appeared to be closely connected to beliefs about how learning takes place, including the conditions necessary for learning. Some participants demonstrated a remarkable degree of change over the course of their involvement in teacher education, while others attended to the role of student ideas only for the duration of their methods courses and then reverted to less constructivist stances during student teaching.
Five distinct characterizations of student ideas emerged in this study, and each is described below in detail. These include:

- student ideas as evidence of content coverage
- student ideas as obstacles to understanding
- student ideas as tools to prime student thinking, interest, and activity
- student ideas as elements of a positive classroom environment
- student ideas as the raw material of learning.

I have identified each of the preservice teachers in the study as oriented primarily to one of these five categories, though throughout their experiences in learning to teach, they often held more than one of these views simultaneously. This was the case particularly during student teaching, as their conceptions about teaching and learning were often undergoing significant change.

**Student ideas as evidence of content coverage**

Five of the participants in this study viewed science teaching primarily as the transmission of content, and as a result, saw student ideas as data that would help them determine whether or not the information delivered by teaching had arrived as intended. This perspective was similar to that of the teachers studied by Morrison and Lederman (2003). An appropriate metaphor for the conception of teaching for this group would be the painting of a room in a house, with school science knowledge as the new paint and misconceptions as the old surface color showing through to indicate where a second coat was needed:
It’s good to know where your students are at. If you’re going to teach something that most of the students have already learned at the 7th or 8th grade level, is it really necessary to go back and do a couple days on that topic? You’re wasting time teaching them stuff, you could move on with a topic, teach them more. (Beth interview, 6 January 2009)

I have found that there are two crucial parts of an inquiry-based lesson that must be done successfully if this approach is to be effective. One crucial part is to set up the students with enough basic information at the beginning so that they can draw their own conclusions after they have made their observations. The other crucial part is to recap what they have learned at the end of the lesson to make sure that any misconceptions are cleared up. (Teaching portfolio, Michael, June 2009)

While the power of teacher explanations to “disprove” misconceptions remained strong among members of this group, over the course of their teacher education programs, they all increasingly indicated a desire to shift responsibility to the student for identifying when their ideas were incorrect. The rationale for this shift was often described in terms of the value of learning science by inquiry emphasized by their programs. Donna’s response to a hypothetical scenario in which a student presents her with the idea that plant mass comes mostly from soil (see Figure 1) represents this view:
So that she in her mind turns her misconception around, because kids are more likely to believe what they’ve discovered than, you telling them...So I would have to you know, be aware of her feelings but also want to encourage her to disprove her misconception. (Donna interview, 8 December 2008)

In this group, notions of eliciting student ideas were tightly interwoven with conceptions about assessment. All of the teacher education programs emphasized the difference between formative and summative assessment, and the prospective teachers in this group interpreted the purpose of assessment as seeking primarily to understand what content had not yet been learned by students. From this perspective, eliciting student ideas helped immensely in this effort, providing evidence of content coverage. This view is supported by the observational data, which shows a clear pattern of an Initiation/Response/Evaluation (IRE) approach to questioning (Cazden, 2001) for teachers in this group.

Such a view of student ideas fit comfortably in teacher-centered conceptions of teaching science. During his student teaching in an anatomy and physiology class, Tyler noted that he appreciated student ideas when they supported his explanations or added depth to his analogies. While he considered some student ideas to be useful in supporting student interest and motivation, he saw little role for student ideas that did not fit with his goal of clearly communicating science content to students. He valued the misconceptions displayed by his students because he perceived that they made it easier for him to replace their incorrect ideas with more scientifically accurate explanations. As a consequence, he...
found it difficult to incorporate the contributions of his students into his teaching, despite a strongly espoused desire to do so. For example, a student raised his hand during one of Tyler’s lectures on cellular respiration to say that he had seen a Discovery Channel program on running that had discussed runners learning to breathe without getting tired. Tyler’s response to this observation was to try to explain it, stating, “Maybe they’re somehow training their mitochondria to do that.” As he continued the lecture, it became clear that an opportunity to capitalize on this student’s interest, or use such knowledge as a conceptual peg on which to build understanding, had been missed.

Many of the prospective teachers in this group took up the language of constructivism from their time in teacher education programs, and often reapplied labels and phrases to their existing conceptions about teaching and learning. For example, “prior knowledge” was often cast simply as what students had already learned, or even in some cases as what content had been “covered” by the teacher. “Constructing knowledge” was used to describe answering questions at the end of a textbook chapter. “Misconceptions” were characterized as incomplete or incorrect knowledge that needed to be revisited by the teacher.

During periods when the teachers in this group were taking coursework, their conceptions of constructivist teaching appeared to be particularly strong. Yet in case after case, many of these ideas about learning were “washed out” during student teaching (Zeichner & Tabachnick, 1981).

For example, Natasha’s changing responses to the scenarios presented in the Conceptions of Teaching Science interview questions offer evidence of a retreat from framing student learning in constructivist terms. One scenario states, “A teacher in ninth
grade at the start of a topic on Arthropods passes around a box of specimens containing insects and spiders. Teacher asks, ‘What can you tell me about these specimens?’” A few weeks into her program, during a time when the focus of the science teaching methods course was on identifying student misconceptions, Natasha clearly viewed the teacher’s question in constructivist terms:

There is science teaching in a way. Because [the teacher] is finding out what they already know about these different insects and spiders. Maybe a child brings up that spiders aren't insects and they're different, or that they all live together…. [As] the students interact and say what they know, they might be learning from each other as well. And the student themselves can be learning that they already know a lot about these insects and spiders. (Interviewer: Would you have said that before taking methods?) Maybe not so much with the teacher just finding out what the student knows. But I would think that the student-student interaction, they'd be learning from each other. (Natasha interview 12 June 2008)

A year later, following Natasha’s student teaching experience, there is little trace of thinking about student ideas in the same scenario:

Yes, students are looking at the insects and spiders, and they’re making observations of them…the teacher kind of put it out there, what can you tell me about the specimens? Kind of facilitating the teaching. But
obviously it’s more the students learning about the insects by viewing the insects and spiders, then the students are you know, learning to kind of see what the similarities between all the insects are, you know, saying that, oh that they’re bugs. And what does it mean to be a bug, kind of thing, so I mean, the teacher’s facilitating the teaching, but in my mind it’s more the insects, the spiders that are teaching of the content type stuff. (Natasha interview 14 May 2009)

This example was also very representative of Natasha’s practice as a teacher during student teaching, and she saw her role as a teacher as someone who should provide the experiences for her students to explore, and then ask them pointed questions as a group to lead them along a path to an explanation of the goals of the lesson. At no time in observations of her teaching or in her lesson plans was there any evidence she elicited student ideas other than to ensure that the content was covered in this manner. Like most others in this group, her appropriation of the constructivist ideas of her methods course had only been temporary.

**Student ideas as obstacles to understanding**

The preponderance of the characterization of students’ ideas as obstacles was noted above in the review of the literature, and this study offers empirical evidence of preservice teachers holding this view as well. For Corrine, Fiona, and Jethro, student ideas were conceptualized either as metaphorical road hazards on a drive to deliver the content, or as blockages in one’s cognitive plumbing that might prevent the free flow of
Preservice Teachers’ Views on Eliciting Student Ideas

information. The value of understanding the ideas of student lay in helping them (and their students) steer clear of misconceptions that would slow them down or block progress entirely.

For example, in discussing the moon observations she had assigned her 6th grade students during practicum, Fiona talked about how she might address the misconception that the phases of the moon were caused by clouds:

You can ask them about it and show evidence of like other things, well do you think that clouds are coming and covering up the same spot at the same time, on a consistent basis, like every month for the past how many thousands of years or whatever? You think that’s possible? That’s when you need to start getting out models and trying to like have them explore for their own. Once you’ve figured that out, then you’ve found your problem and what you need to work on, what misconceptions you need to kind of smash. Cause that’s what’s standing in the way, right there. (Fiona interview, 29 Jan 2009)

Though Fiona is viewing student ideas as a blockage to understanding in this example, she also is offering evidence that she is considering a misconception as more than just an incorrect answer, and attends to the need for students to construct a better understanding based on evidence. Yet like Natasha above, Fiona leaves behind this brief attention paid to student ideas once methods class gives way to student teaching.
Jethro similarly describes a role that student misconceptions might play in describing his preparations to teach a physics lesson on dynamic equilibrium:

I would definitely have to look up misconceptions for dynamic motion somewhere if I was preparing a lesson of that sort, and that would give me some ideas. *(Interviewer: How would that influence your planning)?* I would be prepared to either ask questions, or have a demonstration, or a lab to try to try to alleviate those misconceptions. *(Jethro interview, 14 Jan 2009)*

For Jethro, eliciting student ideas was a means to assess student understanding, and like most prospective teachers in the study, over time he shifted the responsibility for identifying incorrect knowledge to his students, though he still felt compelled to ensure that students left class in possession of the right answers:

The fact that I’m giving the students an opportunity to tell me what they think and I can either choose to confirm or not confirm or sidestep it completely until a later point in time. Because I’m not afraid to let the students stumble a little bit and wait till tomorrow for the right answers. *(Interviewer: What is important about them telling you what they think?)*

For my ability to see if they have misconceptions, which I then need to correct. *(Jethro interview, 7 Jun 2009)*
When asked how he would do this, he replied that different instructional strategies such as inquiry-based activities, lecture, and homework assignments all offered opportunities to correct misconceptions. Though he primarily viewed misconceptions as obstacles, clearly he was also viewing them as evidence of content coverage in the same manner as the previous group.

From this perspective, designing lessons that sought to prevent new misconceptions from arising made a great deal of sense. Characteristic of this view is Corrine’s description of how she would help a student test her idea that conservation of mass holds for plant growth:

I don’t want to set her up to reinforce the misconception that she has. I want to set her up so that it goes the other way, so that she makes sure she accounts for water, to make sure she accounts for anything else where, I guess we’d probably do the experiment, and hopefully that when she finds out that—same amount of soil, different amount of plant—everything what, are the possible other things. Where else might [the mass] be coming from. (Interviewer: How is that different from telling her the answer)? This is something she experiences, she does this herself. The danger comes in if I let her do this and she...you know, this day the soil is moist, and this day the soil is dry, she’s reinforced her misconception. And that’s going to be much more powerful than me saying no. (Corrine interview, 26 May 2009)
In fact, members of this group expressed the view at various times throughout the study that one of the worst things a teacher could do was to engage in a classroom activity that resulted in new misconceptions about science concepts.

**Student ideas as tools to prime student thinking, interest, and activity**

Almost all of prospective teachers in the study used short activities to begin their classes, a practice that was encouraged in each of their four science teacher education programs. These activities generally took the form of a “do-now” or other task that students were assigned in the first few minutes of a period as a way to transition from hallway passing into being in the classroom. For two of the participants, this idea of priming student thinking for learning was the major purpose of eliciting student ideas, and the process of doing so served as a metaphorical lubricant for other actions. From this perspective, a teacher did not necessarily need to do anything with the ideas once they were elicited; the act of eliciting them was a purpose in itself. Both teachers in this category also saw the elicitation of student ideas in terms of evidence of content coverage as noted above, however the primary purpose of creating a space for student ideas in class was to get students in the frame of mind to engage with the subject matter.

In the case of Elise, her attention to eliciting student ideas for purposes of interest and engagement remained constant throughout her preparation. Early in her program, during the period of time that she was enrolled in her science methods course, Elise used a constructivist framing class to articulate her response to one of the scenarios:
Figuring out what the students already know…is a part of teaching students because then the students remember what they have and what they can build on. And it also helps focus the teacher on what things need to be gone over, if there’s any misconceptions…if you get students talking, then they’re more receptive to new information, they’re processing things as they go along. I really think you need to get the students involved in the lesson or they’ll tune out in ten minutes. (Elise interview, 14 October 2008)

Elise’s views on student ideas developed a much more pragmatic quality by the end of student teaching, and she comments on the same scenario in much different terms:

Passing around a box of springs can be physics teaching because I’m assuming that they follow up next with something about forces. I’m assuming it’s an interest-catching thing. Touch this and play with that and then tell me about it. (Elise interview, 3 June 2009)

In the earlier interview, she referred to student ideas in terms of the interest generated by cognitive conflict:

Misconceptions need to be addressed in a very dynamic way so that the students can see what they expect to happen and have it not work that way. They need to have their misconception put in front of them to say
okay, this isn’t what really happens, this is what’s going on. (Elise interview, 14 October 2008)

In her student teaching however, there was little evidence of Elise eliciting student ideas to inform her instruction. Though she saw her role as a physics teacher primarily as creating and guiding students through cognitive conflict situations, she did not attend to students’ ideas in particular. Rather, she perceived these situations as a means to foster interest and enthusiasm for physics, and it appeared that she viewed her teacher education program’s focus on misconceptions as a way to help identify demonstrations that would serve these motivational ends.

Gillian also saw the priming of student interest as the main reason for incorporating student ideas and misconceptions into her teaching, at least initially. In talking about how to motivate students to learn, she stated:

You have to get them excited it about it somehow…You have to find a way to relate their interests and tie that into what you're teaching… If you're outside and you're doing fieldwork on the prairie and the reason they don't want to be there is they're from the city, and they don't like being outside. They're afraid of bugs, whatever. You have to show them, you have to get them into the field work, you have to say, "Look here's a bug, touch the bug, it's not going to hurt you," you have to push their boundaries a little bit to see if that will help them overcome their fears, get
them motivated, or pique their interest in what they're doing. (Gillian interview, 3 June 2008)

Unlike Elise, Gillian’s idea of addressing misconceptions as a way to increase motivation for learning science carried over into her student teaching. She reported that the idea of using discrepant events was new for her, and that she incorporated them into her lessons frequently. Though she saw that demonstrations and similar activities often seemed to increase student motivation, she saw greater value in the fact that they were able to get her students thinking:

I would do a demo and say, well how did this happen? And they would have to figure it out and kind of go into the concept…When we were talking about friction and forces, I intertwined the pages of two notebooks together, and I had students up in the front of class trying to pull them apart. And I said, well why is that? What’s going on? …We had talked about the definition of friction, so after they tried to pull them apart, they kind of looked at the definition of friction and said, ‘Oh, maybe that’s the force that’s in between the pages of the notebook,’ and they came to the conclusion that that force of friction was so strong that they actually couldn’t pull them apart. (Gillian interview, 10 June 2009)

Though Shane’s case will be discussed in more detail below, he also saw the elicitation of student ideas as a way to prime his students for thinking about the content.
One warm-up activity he used with his students at the beginning of a unit on energy featured the writing prompt: “List or write down any ideas you have about energy.” After a few minutes, he compiled students’ responses on the front board, and noted that most “referred to people using, having, or ‘running out’ of energy.” He then showed a PowerPoint presentation on the different forms of energy, and for the remainder of the period he demonstrated to the students how to draw bar charts describing energy storage and transfer in various situations, and the initial list of ideas were not revisited. Later he described the purpose of this activity as a way to get students thinking about energy in preparation for the day’s topic.

**Student ideas as elements of a positive classroom environment**

Though Roberta was not the only participant to attend to creating a positive classroom environment, she was alone in viewing the major benefit of eliciting student ideas as affective, in that doing so contributed to students’ feelings of comfort and worth in the classroom. The airing of student ideas thus served as metaphorical icebreakers to meet the socio-emotional needs of her students. “In order to learn,” she told me prior to student teaching, “you need to be comfortable,” (Roberta interview, 22 Jan. 2009). Her enactment of this idea had a democratic dimension, which often was made visible through interactions with students. During her full-time student teaching, Roberta came to see the rationale for eliciting student’s prior knowledge as similar to that of assessment, namely, to understand student thinking so as to inform the planning of future instruction. Yet the socio-emotional needs of her students always remained in the
forefront of her pedagogical reasoning, as in this example where she recounted a talk she had given to her high school students:

Most of you juniors are going to be taking the ACT, so you have to know how to take multiple choice. But, that’s secondary to being able to learn chemistry and be able to have the time and the means to demonstrate that you’ve learned what I want you to learn. And part of that is the way that the assessment is designed, and part of that I think is the time I give you to do it and the environment that I give you to do it in. I don’t want you to feel stressed about it, because when you’re stressed, you don’t do your best work. (Roberta interview, 11 December 2008)

Throughout the study, Roberta referred to misconceptions as barriers to understanding, much in the same way participants in the second group did. Initially, she viewed misconceptions as something that ought to be addressed with a correct scientific explanation. In an interview prior to student teaching, Roberta was presented with a scenario in which a hypothetical student shares her idea that salt speeds up boiling and should therefore be considered a catalyst:

First of all I’d tell her that that was a good observation that she made, but there’s a distinction between a catalyst, and I would talk about what a catalyst actually does, and then see if she still thinks that’s a catalyst. And then introduce, kind of talk about, boiling point elevation, freezing point
depression…I don’t know how in depth I would go with it… *(Interviewer: Some sort of explanation?)* Yeah. Like I wouldn’t just let that sit. *(Roberta interview, 18 September 2008)*

In this case, Roberta felt compelled to address the misconception by discussing the proper science idea. Leaving the misconception to “sit” was undesirable because to Roberta, the absence of teacher intervention only reinforced the misconception, making it that much harder to dislodge at a later time.

During Roberta’s half-time student teaching, her methods course spent significant time on the role of prior knowledge and student misconceptions for learning. Her response to the same scenario immediately following this course was more consistent with the orientation of her program, in that she recognized the need to take student ideas into account when designing instruction:

> She’s obviously excited about it so she’s going to think about it, and then she might develop some misconceptions that I would not have fun trying to unwind later when we do hit colligative properties. I would want to correct it right away. Not correct it, but talk about it. *(22 January 2009)*

It is telling that Roberta places the responsibility on herself to “unwind” the student’s misconceptions. Clearly, she recognizes the need to elicit further information from the student in her response, though she does not indicate how this would influence her instruction. A portfolio entry produced from one of her chemistry lesson plans offers
further clues to her thinking, and for the first time in her practice, it is apparent that she is incorporating the elicitation of student ideas into her assessments:

Observing student thinking as it progresses and changes is important from an instructor's standpoint because it allows them to analyze where students are understanding and where they may be struggling. This tells the instructor in what direction instruction should go. (Teaching portfolio, Roberta, May 2009)

In her portfolio writing, Roberta used the discourse of conceptual change teaching advocated by her science teacher preparation program, yet her approach was limited to using student ideas to make decisions about which information to communicate to students next. This made it all the more puzzling that this orientation disappeared entirely from her response to the salt-as-a-catalyst scenario a semester later, after the completion of her full-time student teaching:

I would first tell the student, I would congratulate them for making really interesting observations that honestly, I don’t think I ever made until someone taught me about boiling point elevation. All that, like colligative properties. If I had the time I would sit down and talk about what is a catalyst versus how do colligative properties work and that is…I would want her to know what a catalyst was, and I would want her to know what
freezing point depression and boiling point elevation were, and how they were different from each other. (Roberta interview, 5 June 2009)

Roberta’s response was much like the one she had given a year earlier prior to student teaching. Rather than expressing a desire to probe for student ideas, her main concerns were that the student be praised for making observations, and that the student understood the correct scientific explanation for the phenomena. In fact, on the final questionnaire, Roberta no longer disagreed with the statement “Teachers who offer clear explanations in class are able to correct student misconceptions about particular science topics,” as she did on the two previous questionnaires. Much like the cases of Elise and Natasha above, Roberta’s conceptions about the role of student ideas in learning seemed to shift toward constructivism during her methods courses, only to retreat to prior transmissionist perspectives again by the end of student teaching.

Roberta clearly saw value in student ideas, which to her served both instructional and affective purposes. At the conclusion of her student teaching, she was clearly able to articulate the instructional perspective, “Knowing what my students themselves already know helps me, as an instructor, to develop learning goals and appropriate instructional activities,” (Roberta interview, 5 June 2009). While the greater worth for Roberta in eliciting students thinking was in building trusting and well-informed relationships with students, she was also beginning to carve a new role for student ideas in her teaching.

**Student ideas as the raw material of learning**
By the completion of their fieldwork, only Armando, Kathy, and Shane expressed the view that student ideas themselves were the raw material of learning, and needed to be attended to for this reason. Like Roberta, they all believed that the way students felt in their classroom was important, yet their approaches tended to emphasize fostering student ownership over the material as a means to attend to their students’ socio-emotional needs. To varying degrees, these three preservice teachers sought to elicit students’ ideas and then incorporate them into instruction. The metaphor of student ideas as clay used by sculptors and potters represents this perspective quite well.

Over the course of the year, Kathy’s ideas about the role of student ideas changed significantly. Before beginning the program she strongly agreed with the statement, “Teachers who offer clear explanations in class are able to correct student misconceptions about particular science topics.” Though she was aware that students had misconceptions about science, she did not see how knowing these would help her teach students any better. In the final interview, Kathy described her initial ideas about student misconceptions: “I though that if you tell students something, and they disagree, then they’ll take your word for it and suddenly understand,” (Kathy interview, 1 November 2009).

After her methods courses, Kathy described how understanding student ideas helped plan instruction, in the sense that a teacher could know what students did and did not know, and thus could fill in gaps in students’ knowledge. While she expressed a preference for letting students answer their own questions, she felt it was the teacher’s responsibility to “head off” any misconceptions students might be forming. Not wishing to simply provide “right answers,” Kathy preferred to guide her students to the point
where they could figure out answers themselves. These practices were quite consistent with the approach advocated in her science methods courses that I observed.

By the end of student teaching, Kathy had expanded her understanding of student ideas in three particular ways. First, she was able to give examples of particular misconceptions students might possess about different topics without much difficulty. Second, she had identified a link between the use of student ideas and students’ motivation for learning. Third, she now began to speak of student ideas as the raw material of learning, rather than as interchangeable bits of information:

[When] the teacher uses a student’s idea to generate discussion, it takes into account what the students are thinking. It’s not just throwing information at the students, but taking their ideas, their preconceptions, and getting them to talk about it and maybe…instead of just telling them the answer, getting them to think about it and come to their own conclusions. (Kathy interview, 27 June 2009)

At the end of her program, Kathy strongly disagreed with the statement that “Teachers who offer clear explanations in class are able to correct student misconceptions about particular science topics.” The tenaciousness with which students hold their science misconceptions had become apparent to her, both in her teacher education courses and in her fieldwork. In stark contrast to her position a year prior, she strongly agreed with the statement “Students learn best if they have to figure things out for themselves instead of being told or shown.” Reading the above account, Kathy confirmed these changes,
stating, “I really do look at the way students learn a lot differently,” (Kathy interview, 1 November 2009).

There was a similar striking change in Armando’s thinking concerning student-teacher interactions, particularly in responding to their questions, ideas, and expressions of prior knowledge. Initially, he felt that teacher explanations were the proper response for student questions, and that teachers should know the answers to these questions. When students raised “incorrect” ideas, it was the teacher’s responsibility to “tell them they are wrong, but in a nice way,” and then to provide them with the correct information (Armando interview, 29 May 2008). Over the first few weeks of the program, this view changed considerably. Armando publicly wrestled with this idea one evening during an interaction with his science methods instructor in class:

In science we actually have to tell them, okay, you’ve got that down, so they can move onto the other thing…how are kids ever certain they’re on the right track, even if they are on the right track, if you never give them confirmation? Now I understand you have to resist, but at some point in the lesson you want a clear…I mean, I feel uncomfortable saying, “tell them,” because that’s the whole point we’re talking about right now, trying not to do that. (Briggstown science methods course observation, 28 June 2008).

By the end of his practicum experience, Armando had not quite resolved this dilemma, but he had begun to recognize that student ideas represented an opportunity for
inquiry. In the interview scenario where a student presents the teacher with the misconception that plants gain most of their mass from the soil (see Figure 1), Armando recalls his previous answer and describes how it has changed:

This is one of those situations where I have a changed idea. Probably in the past I would have told her, oh you’re wrong, and told her the reasons why you’re wrong…But the fact is that most of the mass of plants comes from the materials they produce, the soil changes in almost microscopic amounts because you just get minerals out of it, nothing else. But since then, my answers have changed, and I’d probably try to give this student, if she really is that interested, another scenario to test that same idea, and see what she comes up with …and maybe even ask here the way she did it and give her the same experiment to do again. Okay, how did you measure the weight, how did you do this or do that? Well, why don’t you try like this and this and that, and show me what you get that way because I’m interested in seeing what you find. (Armando interview, 20 January 2009)

The above is consistent with the Armando’s intended goals of learning to take his lessons—as he put it—in “the direction the kids want it to go.” Though I often witnessed him eliciting students’ conceptions about scientific phenomena and encouraging his students to explore the implications of these ideas, he found it much more challenging to enact this pedagogy in meaningful ways with the class as a whole than he did when working one-on-one with students.
Shane represents something of an unusual case in the sense that his own high school physics teacher taught in what he described as “a very constructivist manner” using the Modeling Instruction curriculum for physics developed at Arizona State University (Hestenes, 1997) and was reportedly well-known and respected by the local physics teacher community. Further, his student teaching placement was in a classroom with another well-regarded physics teacher using the same Modeling Instruction curriculum. Shane entered his year of fieldwork already convinced about the value of student ideas, and from the beginning saw the elicitation of these ideas as central to the act of teaching. He also possessed a firm understanding that explanations alone may do little to address misconceptions about science phenomena, and his language was often quite metacognitive. For example, in the first interview he discussed his own performance on the Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992) as a high school student in terms of the ideas about motion that had changed for him in physics class.

His description of how student ideas relate to pedagogy is described in a portfolio entry during his half-time student teaching:

Effectively eliciting preconceptions communicates to the teacher the areas that may challenge students or pose problems to the learning of designated learning objectives. With prior conceptions in mind, the teacher can design or modify instruction that attempts to change or build upon former student thinking. Eliciting preconceptions also gives the student the opportunity to articulate their ideas with respect to the learning objectives.
As students develop understanding in certain domains, the teacher and the student can then compare new understandings with the elicited prior conceptions to measure the learning that has taken place as a result. (Teaching portfolio, Shane, January 2009)

A common feature of his practice during this time, as well as later during full-time teaching, was that he would often ask student to “explain their thinking.” He used portable student whiteboards extensively (as did his cooperating teacher) in order to have his students “make their thinking visible,” (Shane interview, 12 December 2008)

During full-time student teaching, Shane had some difficulty putting this philosophy into practice, as the day-to-day tasks of teaching often intruded into his well-laid plans of exploring the ideas his students brought to class. This issue of enactment—that is, knowing how to put teaching knowledge into action within the complex environment of the classroom—is a well-documented problem in learning to teach (Hammerness et al., 2005; Kennedy, 1999), and appeared to be an issue for Kathy, Armando, and Shane alike. In all of their cases, moving from individual to collective elicitation of ideas was a challenge, and each struggled in their own way to find a place for working with student ideas within the larger domain of the classroom.

Discussion

To summarize the above findings, each of the fourteen prospective teachers in this study displayed a primary orientation toward one of five views concerning the value and role of student ideas in teaching secondary science. These orientations included viewing
student ideas as evidence of content coverage, as obstacles to understanding, as tools to prime students thinking, interest, and activity, as elements of a positive classroom environment, and as the raw material of learning. As has been shown, these views were not static over the duration of individuals’ teacher preparation programs.

While all saw the elicitation of student ideas as important in some way during their teacher education, each of these perspectives held different pedagogical implications. It is also clear from the data that while participants often held multiple conceptions about the purposes of eliciting student ideas, their overall orientation to student thinking correlated strongly with their conceptions about teaching and learning as they progressed through their respective teacher education programs. In this section I discuss three different aspects of these findings in terms of science teacher education: the identification of a potential learning progression, the transitory nature of constructivist thinking, and the role of content knowledge in working productively with student ideas.

A potential learning progression

These data lend support to the notion by Thompson et al. (2009) that preservice secondary science teacher learning about the role and value of student ideas may be described as a learning progression. Duncan and Hmelo-Silver (2009) describe learning progressions as having upper and lower anchors, with multiple pathways between them possible. In the case of the preservice science teachers in this study, the lower anchor may be represented by an acceptance that students’ ideas have a role to play in science learning. The upper anchor may be considered a more sophisticated view of student ideas as the raw material of learning, and include procedural knowledge on how to effectively
elicit student ideas and successfully incorporate them into one’s teaching so that students learn the intended science content. Taken together, this terrain represents an important epistemological shift for prospective teachers, who may enter teacher preparation with a conception of science knowledge as transferable from one individual to another. A worthy goal for science teacher education is for prospective teachers to make the shift from that perspective to viewing knowledge as “personally constructed and socially mediated,” (Windschitl, 2002, p. 137).

Keeping in mind that learning progressions remain “conjectural models” (Duncan & Hmelo-Silver, 2009, p. 607) and do not necessarily occur as linear sequences, in the present study it is clear that some understandings did appear to precede others. Therefore, the above list has been structured in terms of least to most sophisticated conceptualizations of the role of student ideas in science teaching. Given the findings, it is also clear that individuals’ primary orientations toward student ideas may not always represent their “high-water mark” in this progression over the course of their teacher education program.

It certainly appeared to be the case that those participants with the most sophisticated understandings about misconceptions offered evidence at different times during their program of viewing student ideas from the less sophisticated perspectives. For example, though Roberta sought to elicit student ideas to create a comfortable classroom environment, she regularly returned to the idea that misconceptions were obstacles to learning. Similarly, Shane viewed student ideas as the raw material of learning, but referenced elicitation activities frequently in terms of priming students for classroom tasks. Conversely, none of the preservice teachers in the first group appeared
to consider student ideas as more than evidence of content coverage. Though they could appropriate the discourse of the more sophisticated views temporarily during coursework, these viewed were not sustained, as will be discussed below.

The above sequence is consistent with the rubric developed by Windschitl et al., (2011), but expands upon it by identifying other purposes to which the participants ascribed importance to students’ ideas. Epistemologically, one could also argue that this learning progression represents a shift in perspective about students’ acquisition of scientific knowledge from unproblematic to problematic (Smith, Maclin, Houghton, & Hennessey, 2000; Windschitl et al., 2011). While only the final category can be considered to be fully consistent with constructivist principles, because only there are the ideas themselves the objects of consideration by teacher and student, it may be the case that the other perspectives are also necessary in terms of the development of preservice teacher thinking about the nature of knowledge itself.

The transitory nature of conceptions concerning constructivist pedagogy

The dynamic and often fleeting nature of participants’ conceptions about student ideas in this study ought to give science teacher educators pause. Throughout this research, many preservice teachers appeared to offer sophisticated ways of thinking about student ideas while they were taking methods courses, only to have those notions disappear after student teaching. This “methods bump” is a serious issue, and it appears that while eliciting student ideas is a pedagogical move that was successfully taken up by most candidates in this study, it was not done so with a common rationale.
It appeared that those who sought to elicit student ideas for evidence of content coverage or obstacle identification also held unclear notions about the purposes of formative assessment. In these cases, formative “feedback” to students primarily consisted of informing them what they still had wrong, and then telling them the correct answer.

The role of content knowledge in working productively with student ideas

There was also an apparent connection between the flexibility of participants’ content knowledge and their ability to respond to student ideas, both in hypothetical scenarios and in practice. Those who provided evidence of having a rich understanding of the subject matter found it easier to anticipate student misconceptions with the content—even if deciding what to do with those misconceptions was more difficult. Those with a more shallow understanding of a particular topic often refocused the conversations about student misconceptions on the practices of science, and away from the science content under discussion. In this way, their students’ misconceptions about science content were usually answered by vague appeals to inquiry. While in some sense this approach is laudable, the net effect was that it did not allow for the explicit comparison of competing ideas, as the teaching for conceptual change literature suggests is necessary (Hewson et al., 1998; Hewson & Lemberger, 2000).

For example, Beth, Gillian, and Natasha all admitted uncertainty as to the source of mass gain in plant growth. In response to a hypothetical student’s question on this topic, all three chose to view it as an opportunity to teach the student about experimental design in science and describe how they would help the student understand hypothesis
testing and systematic observations. In contrast, Corrine, who had a Ph.D. in molecular genetics, similarly expressed a preference towards having the student test the idea by experiment, but then also articulated some of the conceptual difficulties the student might have in that effort:

We have a notion of food, and a lot of students have a notion of food, and they make the switch, ‘our food is like plant food.’ You take it in, it makes us grow. Plant food you pour it onto the soil and it makes it grow. They don’t make that connection between photosynthesis and mass accumulation. (Corrine interview, 26 May 2009)

Corrine’s understanding of the ways in which the student might get things wrong in their thinking is directly related to her knowledge of the content (Abell, 2007; Ball, Thames, & Phelps, 2008). Yet this study also clearly shows that this ability to anticipate and understand the sources of student misconceptions did not always indicate an ability to work productively with student ideas in the teaching of science, though it may in fact be a necessary precondition. Armando, who had worked in a neurobiology lab as an undergraduate, was quoted above saying “I’d probably try to give this student, if she really is that interested, another scenario to test that same idea, and see what she comes up with.” Though he is aware of potential misconceptions, he explicitly refers to testing the student’s idea, rather than just focusing on procedures.

While Shulman’s (1987) notion of pedagogical content knowledge aptly describes the knowledge structures needed by teachers to respond to specific teaching situations
like Armando’s above, the description of specialized content knowledge by Ball et al. (2008) as a sub-domain of the content knowledge unique to teaching seems more appropriate to describe the different ways in which students might theorize about scientific phenomena in ways that give rise to misconceptions. Clearly, more research is needed on this connection between subject matter knowledge and teachers’ ability to respond productively to the ideas of their students.

Conclusion and Implications

In describing some of the trends that have impacted the view of inquiry in science education over the past 50 years, Duschl and Grandy (2008) note the shift from “a view of science that emphasizes observation and experimentation, to a view that stresses theory and model building and revision,” (p. 7). This shift has important implications for the role of student ideas in the learning of science, as they are the raw materials out of which theories and models are built and revised in the minds of learners. In fact, if student misconceptions are viewed as models with explanatory and predictive power themselves, teaching strategies that seek to test and revise these models may prove quite powerful. Such an approach is deeply consistent with current efforts in science education reform, particularly those that foreground model-based instruction (Windschitl, Thompson, & Braaten, 2008), teaching for conceptual change (Hewson et al., 1998), and the principles of learning science outlined in recent major research reports and standards documents (Bransford & Donovan, 2005; National Research Council, 1996).
Yet these efforts appear to be hampered by the mixed messages being sent by science teacher educators and science education researchers. While the attention given to prior student understandings in methods courses is a promising development, the frequent portrayal of student misconceptions as obstacles rather than resources in the literature is likely echoed in science teacher education programs across the country. If science teacher education is to be reframed to focus even more closely on student thinking, it is imperative that science teacher educators clearly represent the productive role of student ideas in teaching and learning, and cast student misconceptions in a light that presents them less as obstacles to learning and more as resources for learning. We can also affirm the cognitive and affective roles that the practice of eliciting students’ ideas can play in the classroom, but if the goal is to better prepare science teachers to teach for understanding, we must also present them with the tools to use their students’ ideas as resources toward this end. Russell and Martin (2007) remind us that as science teacher educators, we must also attend to the ways in which we elicit and use the ideas that our prospective science teachers have about teaching: “The research literature confirms that it is entirely counterproductive to simply transmit such lessons to teachers as content,” (p. 1161).

This paper originated in a broader study that examined how preservice secondary science teachers learned to teach in diverse classrooms, and it is worth noting the clear parallels between the ways that preservice teachers characterized student misconceptions and the ways in which the same individuals viewed the pedagogical implications of student diversity. Both in the literature and in practice, student diversity is often cast in teacher education in terms of obstacles or resources ( Hollins & Guzman, 2005; Zeichner,
just as student misconceptions were shown to be in this study. I would argue that preparing science teachers to view student diversity as a resource is just as important as preparing them to do the same with their students’ misconceptions. It even seems likely these goals represent two sides of the same coin. The conceptions and patterns of thinking that students hold as a result of their life experiences undoubtedly influence and structure their learning in science. This study lends support to the assertion by Levin et al. (2009) that one of the primary tasks of science teacher educators ought to be in preparing teachers to view student thinking itself as the raw material of their work.

It seems reasonable that the perspectives on student ideas described in this paper might also be held by science teachers across the professional continuum, and further research might explore the ways more experienced teachers work productively with student ideas to foster deeper learning. A broader research agenda might look to other subject areas to understand those aspects of working with student ideas that are disciplinary in nature, and which might suggest a common approach to student misconceptions across a wide variety of school subjects. Further research might also explore to what extent and in what forms attention to student conceptions is paid in science teacher education programs. Finally, Shane’s advanced starting point in terms of working with student ideas gives our field a glimpse of issues that have yet to gain prominence, but that science teacher educators might anticipate as science education reforms begin to bear more fruit. Though Shane clearly understood the value of his students’ ideas and sought to incorporate them productively into his teaching, his struggles to manage the complexity of the classroom limited his ability to extend his attention to student thinking to the whole class. Clearly, the ability to elicit and
understand the role of student ideas in teaching and learning is but one tile in the larger mosaic of learning to be a science teacher.

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Table 3. Sample case summary: Fiona

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Figure 2. Average values of participants’ level of agreement with the statement: “Teachers who offer clear explanations in class are able to correct student misconceptions about particular science topics,” during time spent in a teacher education program.
<table>
<thead>
<tr>
<th>Characterization of Student Ideas</th>
<th>Name</th>
<th>Teacher Education Program</th>
<th>Certification Program &amp; Area</th>
<th>Age Range</th>
<th>Self-described race/ethnicity and gender</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. As evidence of content coverage</td>
<td>Beth</td>
<td>Brigstown University</td>
<td>Biology, Broadfield Science</td>
<td>20-24</td>
<td>White female</td>
</tr>
<tr>
<td></td>
<td>Donna</td>
<td>Clayton State College</td>
<td>Biology</td>
<td>25-29</td>
<td>Asian/Latina female</td>
</tr>
<tr>
<td></td>
<td>Michael</td>
<td>Clayton State College</td>
<td>Biology</td>
<td>20-24</td>
<td>White male</td>
</tr>
<tr>
<td></td>
<td>Natasha</td>
<td>Brigstown University</td>
<td>Biology, Broadfield Science</td>
<td>20-24</td>
<td>White female</td>
</tr>
<tr>
<td></td>
<td>Tyler</td>
<td>Clayton State College</td>
<td>Biology, Physics</td>
<td>20-24</td>
<td>White male</td>
</tr>
<tr>
<td>2. As blockages to understanding</td>
<td>Corrine</td>
<td>Acacia College</td>
<td>Biology, Broadfield Science</td>
<td>35-39</td>
<td>White female</td>
</tr>
<tr>
<td></td>
<td>Fiona</td>
<td>Brigstown University</td>
<td>Biology, Earth Science</td>
<td>20-24</td>
<td>White female</td>
</tr>
<tr>
<td></td>
<td>Jethro</td>
<td>Brigstown University</td>
<td>Physics, Computer Science</td>
<td>50-54</td>
<td>White male</td>
</tr>
<tr>
<td>3. As tools to prime student thinking, activity, and interest</td>
<td>Elise</td>
<td>Clayton State College</td>
<td>Physics</td>
<td>25-29</td>
<td>White female</td>
</tr>
<tr>
<td></td>
<td>Gillian</td>
<td>Brigstown University</td>
<td>Biology, Chemistry</td>
<td>25-29</td>
<td>White female</td>
</tr>
<tr>
<td>4. As elements of a positive classroom environment</td>
<td>Roberta</td>
<td>Delorenzo University</td>
<td>Chemistry</td>
<td>20-24</td>
<td>White female</td>
</tr>
<tr>
<td>5. As the raw material of learning</td>
<td>Armando</td>
<td>Brigstown University</td>
<td>Biology, Chemistry</td>
<td>20-24</td>
<td>Dominican (Republic) male</td>
</tr>
<tr>
<td></td>
<td>Kathy</td>
<td>Brigstown University</td>
<td>Biology, Environmental Science</td>
<td>20-24</td>
<td>White female</td>
</tr>
<tr>
<td></td>
<td>Shane</td>
<td>Delorenzo University</td>
<td>Physics</td>
<td>20-24</td>
<td>White male</td>
</tr>
</tbody>
</table>
### Table 2
Timeline of data collection and teacher education program work in methods courses and fieldwork.

<table>
<thead>
<tr>
<th>Program &amp; Participants</th>
<th>Summer Year 1</th>
<th>Fall Year 1</th>
<th>Spring Year 1</th>
<th>Summer Year 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia College (Corrine)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methods coursework &amp; fieldwork</td>
<td>Teaching Science (3 credits)</td>
<td></td>
<td>Full-day student teaching at the high school level. Full semester following the school district calendar</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 total hours of practicum in two settings, one middle school and one high school. Mostly observation but with opportunity to design and teach lessons.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data sources</td>
<td>Questionnaire (1st)</td>
<td>Interview (1st) Observation of exit interview for Teaching Science class</td>
<td>Questionnaire (2nd) Interview (2nd) Observations of full-day student teaching</td>
<td>Questionnaire (3rd) Interview (3rd) USB drive of coursework files including portfolio</td>
</tr>
<tr>
<td>Briggstown University (Jethro, Kathy, Armando*, Beth, Natasha, Fiona, &amp; Gillian)</td>
<td>Science Methods I (3 credits)</td>
<td>Science Methods II (6 credits)</td>
<td>Full-day student teaching at the high school level. Full semester following the school district calendar</td>
<td></td>
</tr>
<tr>
<td>Methods coursework &amp; fieldwork</td>
<td></td>
<td>50 hours of practicum in urban middle school classroom. ~10 hours as lead teacher (5 credits)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data sources</td>
<td>Questionnaire (1st) Interview (1st) Weekly observations of Science Methods I classes</td>
<td>Questionnaire (2nd) Weekly observations of Science Methods II classes Observations of practicum fieldwork</td>
<td>Questionnaire (3rd) Interview (2nd) Observations of full-day student teaching</td>
<td>Questionnaire (4th) Interview (3rd) USB drive of coursework files including portfolio</td>
</tr>
</tbody>
</table>
### Table 2 (continued)
Timeline of data collection and teacher education program work in methods courses and fieldwork.

<table>
<thead>
<tr>
<th>Program &amp; Participants</th>
<th>Summer Year 1</th>
<th>Fall Year 1</th>
<th>Spring Year 2</th>
<th>Summer Year 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Clayton State College</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Donna, Michael, Elise, &amp; Tyler***)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methods coursework &amp; fieldwork</td>
<td></td>
<td>Science Methods (3 credits)</td>
<td>Full day student teaching in a high school. Full semester following the school district calendar</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 total hours of practicum in two settings, one middle school and one high school. Mostly observation but with opportunity to design and teach lessons.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data sources</td>
<td>Questionnaire (1st)</td>
<td>Questionnaire (2nd)</td>
<td>Questionnaire (3rd)</td>
<td>USB drive of coursework files &amp; electronic portfolio</td>
</tr>
<tr>
<td></td>
<td>Interview (1st)</td>
<td>Observations of full-day student teaching</td>
<td>Interview (2nd)</td>
<td></td>
</tr>
<tr>
<td><strong>Delorenzo University</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Roberta &amp; Shane)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methods coursework &amp; fieldwork</td>
<td>[In this two-year certification program, a 3-credit Science Methods I course was taken by Delorenzo students the previous spring. Two observational practica were completed over the two previous semesters, and consisted of 40 hours in a middle school and 40 hours in a high school.]</td>
<td>Science Methods II (3 credits)</td>
<td>Full-day student teaching in a high/middle school (whichever was not done prior semester). Full semester following the school district calendar</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Half-day student teaching in the mornings, coursework in the afternoons. Middle/high school following school district calendars. One middle and one high school placement.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data sources</td>
<td>Questionnaire (1st)</td>
<td>Questionnaire (2nd)</td>
<td>Questionnaire (3rd)</td>
<td>Questionnaire (4th)</td>
</tr>
<tr>
<td></td>
<td>Interview (1st)</td>
<td>Interview (2nd)</td>
<td>Observations of full-day student teaching</td>
<td>USB drive of coursework files &amp; electronic portfolio.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Observations of half-day student teaching</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Armando dropped out of the program prior to full-time student teaching.
** Tyler began student teaching a year after his methods course and practicum fieldwork. His data is limited to before and after full-time student teaching only.
TABLE 3  
**Sample case summary: Fiona**

<table>
<thead>
<tr>
<th>Overall view of misconceptions:</th>
<th>Misconceptions are wrong ideas that can be set right by discrepant events and experiences with explanations that cause cognitive conflict. Identifying misconceptions helps a teacher decide what problem (generally) to work on.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changes over the course of teacher education:</td>
<td>In her practice, brief flashes of attention to student ideas gave way to paying them no heed during student teaching. The understandings she articulated in interviews similarly disappeared.</td>
</tr>
<tr>
<td>Summary:</td>
<td>Fiona's first interview took place after the methods class had introduced working with student ideas, and her responses were beautifully aligned with constructivism. Over the two next semesters, this wore off completely to leave the definition above, and little to no attention to student ideas showed up in her teaching or in the conversations. Talk about misconceptions at that time was shorthand for “wrong ideas.”</td>
</tr>
</tbody>
</table>
References


Preservice Teachers’ Views on Eliciting Student Ideas


Preservice Teachers’ Views on Eliciting Student Ideas


RESERVICE TEACHERS’ VIEWS ON ELICITING STUDENT IDEAS


Footnotes

1 This group at the University of Washington-Seattle has developed an extensive set of tools for working with preservice science teachers as part of their ongoing research. These are currently available at http://tools4teachingscience.org/ along with further descriptions of the project. A tool specifically intended for helping preservice teachers understand what to do with student ideas once they are elicited may be found at http://tools4teachingscience.org/pdf/Working_on_students_ideasX.pdf

2 These protocols were originally focused on preservice teacher thinking about in writing and mathematics.

3 The teacher education program that enrolled Roberta and Shane differed from the others in that it was two years long, with the second year consisting of half-time student teaching and coursework in the fall semester, followed by full-time student teaching in the spring. Though I worked as a teacher educator in this program during this time, I had no supervisory authority over either of them, and the informed consent procedures approved by the university Institutional Review Board ensured that there were no ethical conflicts in this research arrangement.

4 Armando only completed his fieldwork practicum before dropping out of the program for financial reasons.

5 As part of the protocol for each of the follow-up interviews, each participant was told, “As we proceed through the interview, if you feel that your answer has changed significantly since a previous interview, please feel free to share that information and perhaps discuss what in the recent past has changed your mind.”