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ABSTRACT

This paper addresses the question of how teachers can support and facilitate conceptual change in student thinking. It begins with a discussion of the multiple meanings of the term conceptual change. An argument is presented for the notion that recent developments in research in science learning have dramatic implications for what students are expected to learn and how they are expected to learn it. These developments also have dramatic implications for how teachers might facilitate that learning. The focus of this paper is on the instructional practices of one teacher and includes a description of the instruction, learning goals, details on the presentation and analysis of data, and student responses to instruction. The study finds that in a very real sense, students in the classroom became metacognitive as a result of the teacher's instruction, taking greater control over the responsibility for their learning than is typically expected of most students. (Contains 22 references.) DDR)

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Learning to Learn Science: Instruction that Supports Conceptual Change

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Introduction

The expectations for students learning science have changed significantly over the past several decades. A great deal of the current expectation involves changes in the way we, teachers and researchers, think about the learning of science in at least two ways; the first relates to what students are expected to learn and to be able to do in science, and the second to the contexts within which students are expected to learn science content. With respect to the first, cognitive models of learning that focused on individual students have guided much of the past research in science learning (e.g., the Conceptual Change Model of Posner, Strike, Hewson, & Gertzog, 1982). This was followed by suggestions for investigating the impacts of non-cognitive factors impacting the learning of individual students (Pintrich, Marx, & Boyle, 1993). With respect to the second, increasing attention has also been paid to notions of the situated nature of learning (Brown, Collins, & Duguid, 1989) in which the contexts of the classroom and beyond play an essential role in the actions of individual students. Many recent studies have been framed by the notion that students and teachers are creating discourse communities within which social aspects of scientific knowledge are co-constructed (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Roth, 1993).

Driver, Asoko, Leach, Mortimer, and Scott (1994) have suggested a theoretical perspective on science teaching and learning that takes into account many of the recent developments in science education research. Driver et al. suggest that knowledge construction within the discipline of science needs to be understood by students as socially constructed. As used here, understanding science implies that learners “‘appropriate’ the cultural tools [of science] through their involvement in the activities of the culture” (p.7). Driver et al. recognize the consequences this position would have for science educators in the following:

[If] learners are to be given access to the knowledge systems of science, the process of knowledge construction must go beyond personal empirical enquiry. Learners need to be

given access not only to physical experiences but also to the concepts and models of conventional science. The challenge lies in helping learners to appropriate these models for themselves, . . . If teaching is to lead students toward conventional science ideas, then the teacher's intention is essential, both to provide appropriate experiential evidence and to make cultural tools and conventions of the scientific community available to students. (p.7).

While the recent interest in situated cognition and the social construction of knowledge has provided valuable insight into classroom science teaching, the strong version of this perspective pays little attention to analyses of the contribution of individual students' performance to group understanding. Cobb (in press), however, advocates what he terms the emergent perspective, one of whose

central assumptions is that learning can be usefully characterized as both a process of active individual construction and as a process of mathematical enculturation...The basic relation posited between students' constructive activities and the classroom social processes in which they participate is one of reflexivity in which neither is given preeminence over the other. In this view, students are considered to contribute to the evolving classroom mathematical practices as they reorganize their individual mathematical activities. Conversely, the ways in which they make these reorganizations are constrained by their participation in the evolving classroom practices. A basic assumption of the emergent perspective is therefore that neither individual students' activities nor the classroom mathematical practices can be adequately accounted for except in relation to the other. (p.3-4).

Although Cobb writes about mathematics classrooms, we believe the reflexivity he describes is compatible with the position of Driver, et al. (1994) and applies equally to science education. Using both perspectives to interpret classroom instruction has the potential to provide a breadth of understanding that neither on its own is able to do. More specifically, in this article we argue that it is valuable to use both perspectives in understanding and interpreting teaching. For example, while there are different emphases between the sociocultural recommendation to "make cultural tools and conventions of the scientific community available to students" and the guideline that the "justification for ideas and for status decisions needs to be an explicit component of the curriculum", one of several guidelines that characterize teaching for conceptual change (Hewson, Beeth, & Thorley, 1997), they are never the less compatible with each other. When they are both used to interpret teaching, they provide an enhanced understanding of how learning occurs. We illustrate this argument by

examining the instruction of Sister M. Gertrude Hennessey, an elementary school science teacher whose students have demonstrated a quality and depth of understanding of science that scientists, science educators, and cognitive psychologists recognize is extraordinary. Sister Gertrude uses central ideas of the conceptual change model in a practice that is also strongly supportive of a student community whose members construct common knowledge in close cooperation with one other.

We also argue that contemporary developments in research in science learning have had dramatic implications for *what* students are expected to learn and *how* they are expected to learn it, and that these in turn have dramatic implications for how a teacher might facilitate that learning. We are particularly interested in understanding how the instruction of a teacher can support students as they examine their thoughts in relationship to the scientific ideas they are studying. Here, too, Sister Gertrude's instruction supports students as they learn to reflect on scientific ideas in powerful and meaningful ways (i.e., to be metacognitive about their own and others' ideas). How Sister Gertrude facilitated metacognitive discourse that allowed her students to talk about their ideas is analyzed in detail.

Thus in this article we address the question: How does a teacher support and facilitate conceptual change in students' thinking? First, we consider the multiple meanings of the term *conceptual change* that are used throughout the article. Then we describe and analyze Sister Gertrude's instruction in light of these multiple meanings. Finally we summarize the findings and consider their implications for learning to learn science.

Multiple Meanings of Conceptual Change

In this article we regard conceptual change as occurring when there are changes in the status of a conception (Hewson, 1981; Hewson & Thorley, 1989). Prototypically, conceptions have been thought of as the declarative and, to a lesser extent, the procedural knowledge of a discipline. A perspective on conceptual change that explained only the latter, and not how students change conceptions, would *a priori* be unacceptable. Yet, while changes of these kinds

are a necessary part of what it means to learn science, we do not believe they are sufficient. In particular, they do not, by themselves, facilitate students' ability to engage in future conceptual change learning, or to approximate the kind of thinking associated with the scientific community. Thus we argue that students may also need to experience conceptual change with respect to their conceptions of what it means to learn science and of scientific epistemology. We consider each of these meanings for conceptual change below, before considering their implications for teaching.

Force, atoms, evolution, and plate tectonics are prototypical exemplars of *declarative conceptions*; thus conceptual change can be used to describe changes in the amount of propositional information a student has regarding a particular scientific idea. If, after instruction, a student could state Newton's Laws of Motion, when before instruction he or she could not, that would represent a change in the student's propositional knowledge. Change might also occur in the number or quality of linkages a learner could ascribe to a particular idea (e.g., on a concept mapping exercise) or in a student's *procedural conceptions* (e.g., how to apply Newton's Laws in an unfamiliar context) or how to determine an inheritance pattern from a field sample of organisms. There are many examples of these sorts of conceptual changes in the research literature (see Pfundt & Duit, 1994).

Next, we believe that in addition to changes in declarative and procedural knowledge, students may also need to experience change in their *conceptions of learning*. One aspect of this change would be reflected in how they talk about their scientific ideas. It should be noted here that we are proposing qualitative differences in how students' ideas are discussed, not in what those ideas might be. At the very least, learners must recognize if scientific ideas differ from their own and if that difference has significance for them. An example of this phenomenon occurred during the teaching of friction and momentum to grade 7 students (ages 12-13) by Robert Tai (Schneps, 1995). Tai's instruction deliberately sought to bring his students' conceptions into conflict with those of the scientific community. Near the conclusion of this

instruction, Tai asked small groups of students to describe their ideas about friction and momentum acting on a ball rolling through a U-shaped track. One group presented the following report through their spokesperson:

Student: We think that, when you drop the ball, it's going to roll almost all the way up but not quite. And then it is just gradually going to go down [with each oscillation]. But we think it is going to take a long time because there is no friction to stop it. And it will go almost all the way up because there is gravity pulling it down really fast and so when it goes up there is no friction to stop it but there is also gravity pulling it down towards the center. And we think that the scientists' ideas are going to be that it is going to go all the way up to the top because friction is what stops it and gravity is what makes it go. Even though we disagree [with the scientific explanation] we think that the science ideas might be true but right now we don't really, we can't really test it. So we still disagree.

Tai: My question is, how do you handle it when your ideas don't agree with the scientists' ideas, but you say the scientists' ideas might still be true? What do you mean by that?

Student: We don't really know [which is true]. But right now we believe our ideas because we don't think we have enough information to say that the scientists' ideas are right. So, we still believe our ideas.

In the excerpt above, the students have shed significant light on their thinking. The spokesperson for the group indicates that she is beginning to grasp (or find intelligible) what she believes the scientific idea to be but that she chooses to retain her idea because she does not know how to test the scientists' idea. Having no means available to empirically test the scientific idea at this time, she is unwilling to accept the canon of contemporary science.

We suggest that the ability of students, like the spokesperson above, to select from among competing ideas involves metacognition (White, 1993; White & Gunstone, 1989), and that the ability to reflect on competing ideas would represent a significant change in what it means to learn science. In the situation presented above, the learner indicated that while her group found the scientific idea initially intelligible, they had no reasons to believe that the scientific idea was any better than their current idea. Hewson and Thorley (1989) described this distinction between the intelligibility and plausibility of ideas as one of status, suggesting that determination of status is an essential component of learning viewed as conceptual change. The ability of students to comment on the status of conceptions represents a kind of conceptual change that, while not linked to specific science content, provides students with a powerful

means of talking about any ideas they currently hold or are considering. Comments about the status of conceptions, like those above, also provide the teacher with information that may be useful when planning instruction to create dissatisfaction with specific components of students' conceptions. Robert Tai could, for example, plan his instruction to focus on the empirical tests used by the scientific community to justify their explanation of the ball rolling in the track. Whether the students' adopt this explanation or not is another matter. When students have developed the ability to reflect on the status of their own and others' ideas, we regard this as evidence of a desirable conception of learning. If initially they did not have such an ability, we would regard its acquisition as a significant conceptual change. From a sociocultural perspective, this would be evidence that they have been involved in activities similar to those that are important in the scientific community when discussing the possibilities inherent in new or competing idea.

Finally, students may need to change their *conceptions of scientific epistemology*. Students need to understand the rationale used by the scientific community to select among competing ideas. Thus, the ability to select and apply a conception consistently, in all cases where that concept ought to apply, represents another level of understanding for a learner. They must understand what the reasons are that support scientific ideas (or those expressed by other students) before they can consider if their thinking should change. In short, if students are expected to examine multiple ideas with the intention that they will be able to choose among competing ideas, they need some criteria upon which to make this decision. The rationale supporting a decision might involve logical forms of arguments, the desire for ideas to be consistent (both internally and externally), relationships among data and ideas (especially discrepant data), and selecting the most parsimonious explanation for phenomena. These are just some of the epistemological commitments of the scientific community that are not normally addressed directly in textbooks but are essential in helping scientists (and students) decide which ideas are accepted. When students develop competence in applying epistemological

standards to their own and others' ideas, we regard this as evidence of a desirable change, a change in their conception of scientific epistemology. From a sociocultural perspective, as before, this would be evidence that they have been involved in intellectual activities that are essentially similar to those in the scientific community.

We have outlined conceptual changes to three different aspects of learning above. While the focus in much of the literature has been on conceptual change of the first kind, we argue in this article that changes in the other kinds of conceptions are not independent of one another. On the contrary, we argue that conceptions of learning and scientific epistemology have a profound influence on the disciplinary conceptions a person acquires. For example, if a learner's conception of learning science is the memorization of information from an external authority, this would dramatically limit the meanings they could ascribe to their own conceptions.

Adopting any individual component of the epistemology of science and changing how you learn requires considerable effort on the part of a learner, or a scientist for that matter. The standards to which scientific knowledge is held are much higher than the standards for pragmatic knowledge. It should also be noted that none of the standards used by the scientific community is derived from an individual. Rather, all of them are conventions developed and agreed upon by the scientific community to validate their ability to explain the natural world. The epistemological standards for learning science in a classroom need to reflect a similar kind of social negotiation among teachers and students. We believe that it is the teachers' responsibility to establish such a context for learning.

Identifying a need for students to acquire conceptions of learning and scientific epistemology outlined above (if they do not already hold them) raises questions about the nature of teaching that is able to facilitate conceptual changes of these kinds. Discussion of the metacognitive, or second order, thinking required in considering the status of ideas and the epistemology of science are not typically part of many science classrooms. A notable exception to this is the Project to Enhance Effective Learning in Australia (Baird & Mitchell, 1986; Baird

& Northfield, 1992). For the kind of learning community portrayed here and in the PEEL Project to occur, students need to speak about their ideas as much as they did with their ideas (Kuhn, Amsel, & O'Loughlin, 1988). The role of a teacher in this kind of classroom changes to include facilitating students' abilities to speak about their ideas (i.e., determining status), helping them to understand and apply standards the scientific community uses to justify ideas (i.e., the epistemology of science), and establishing a separate epistemology for the classroom that is, in some ways, similar to the scientific community.

A teacher's instruction should include efforts to address the socially agreed upon epistemologies of science if we expect students to understand these ideas and engage in the practices of the scientific community. Telling students about the epistemological standards of the scientific community is unlikely to help them apply those standards when learning science content. Students need to learn the epistemology of science by applying these standards in the context of learning science content. One pedagogical implication arising from the discussion presented here is, how can a science teacher present the epistemology of science to students? Seldom in our experiences have we observed a science teacher directly address the epistemology of science through instruction. The account of instruction that follows is a notable exception.

Description of instruction

This section describes, in very general terms, the approach Sister Gertrude takes toward science instruction. Sister Gertrude's instruction is marked by her desire to facilitate and support discourse among her students that allows them to talk about their developing science ideas in increasingly powerful (i.e., scientific) ways (Hennessey, 1991, 1993; Hennessey & Beeth, 1993). A full-time elementary school science teacher, Sister Gertrude teaches all students in grades 1-6 (ages 5-11). Students in her classroom study force and motion, the particulate nature of matter, heat and temperature, and human anatomy and physiology over several consecutive years. Although it was quite apparent to us that Sister Gertrude's subject matter knowledge of these topics was extremely well founded, she did not use her understanding

of science concepts to present herself as the authority on science content to her students. She used it instead to choose the central topics that comprised her curriculum and to monitor and interpret the various actions she required of her students. At the very heart of the actions she expected of her students were seven learning goals she presented to them at the beginning of each academic year (see Table 1). Note that none of the learning goals in Table 1 is linked directly to science content. Each of these learning goals does, however, speak to a student's ability to reflect on the ideas they have at any given point in time. In other words, Sister Gertrude expected students to determine the status of ideas, offer reasons underlying an idea, and learn some of the epistemological commitments of the scientific community as they studied science a variety of science topics.

TABLE 1

Sister Gertrude's Learning Goals

1. Can you state your own ideas?
2. Can you talk about why you are attracted to your ideas? ("the what as well as the why")
3. Are your ideas consistent?
4. Do you realize the limitations of your ideas and the possibility they might need to change?
5. Can you try to explain your ideas using physical models?
6. Can you explain the difference between understanding an idea and believing in an idea?
7. Can you apply intelligible and plausible to your own ideas?

Sister Gertrude planned each unit of instruction by identifying what she believed to be conceptually difficult topics for students to learn. Her instruction frequently began with students exploring physical phenomena in a laboratory setting. For example, at the beginning of the force and motion unit students observed and categorized the motions of twenty different objects demonstrated by Sister Gertrude. Following this demonstration, students chose one object to investigate with the task of determining how that object was moving. Returning to whole class discussion, Sister asked the students to first focus their attention on describing the motion of their object (e.g., it speeds up, slows down, is not moving). Later, she asked them to

explain how the motion of the object changed, if it did, and what forces might cause an object to change its motion.

Students frequently worked in self-selected groups of 3-5 and as a whole class to define what the central terms of the topic meant to them. These could, for example, be scientific terms such as *force* or terms about learning such as *intelligible*. She would then combine all of the students' ideas to produce one master list representing the ideas of the class on the topic without passing judgment on the students' initial ideas. Typically at this point the students and teacher would have produced a list of single words that characterized a particular topic. Using this list, Sister asked the students to assemble into their small groups to determine which words should stay on the list and which should be removed, with the caveat that students needed to give reasons for either removing a word from the list or retaining a word on the list. Returning to a whole class setting, groups of students shared their thoughts regarding words on the list and negotiated which words would remain on the list with their colleagues. In the process of socially negotiating the list of words over two or three weeks, the students began to speak not in single words but in phrases that justified why words should be retained. As this process continued, Sister began to write down the statements students offered in support of their developing ideas. These statements then went through a similar process to that used with the word list until the students could agree on how a term would be used in this classroom.

Outside of class, Sister used the students' ideas represented by their developing lists to plan her instruction (Hennessey, personal communication). She was aware of many of the conceptions students might express during the elicitation phase of her instruction as a result of her professional experience and her reading of science education research literature. Combining her knowledge from past experience with ideas the student groups expressed, she planned what to address first through her instruction. She would frequently isolate one idea that she knew from experience was problematic in terms of learn but had the potential, if learned, to facilitate change in students' conceptions. For example, when studying force and motion she

asked her students to describe the motion of objects scientists would describe as at rest, moving with constant velocity, changing acceleration, and moving in a circle. Following the iterative process described above, the students typically settled on categories of motion labeled not moving, speeding-up, and slowing down. With the students' categories in mind, she chose to focus first on objects at rest (e.g., a book on a table) because it is theoretically easier for students to understand that balanced forces explain the motion of objects at rest. From this students could be expected to understand rather quickly that unbalanced forces would cause a change in the motion of an object at rest. The instruction that followed, on unbalanced forces, was designed to focus on changes in the velocity of a moving object, not merely in determining *if* an object was or was not moving. Throughout all of her instruction, Sister Gertrude facilitated discussion of the students' ideas for extended periods of time, up to five or six weeks in some cases. It was only when she determined that the students could "go no farther with their ideas" that she provided structure in her instruction that led to the ideas of the scientific community. Recognition of these points in time were crucial in terms of the students' learning and the instructional choices of the teacher. Both are explored in the data analysis section that follows.

The learning goals presented by Sister Gertrude create an epistemology that reflects the significant role played by learners' ideas. In this classroom, students needed to represent their ideas verbally or symbolically, provide reasons to support an idea, be consistent unless they had reasons to change an idea, determine the status of their ideas as well as any idea presented to them, and recognize the possibility that ideas might need to change. Embedded in these goals are conceptions of learning and scientific epistemology of the kind that we discussed above. Thus, for students in this classroom, the overall goal of learning was to compare their ideas first to those of their peers and then to those of the scientific community. Collectively, these learning goals aim to establish an intellectual environment for learning that is similar to that of the scientific community.

The learning goals are all expressed from the perspective of an individual learner. Yet, as described above, Sister Gertrude's instruction requires that her students acquire, and demonstrate their competent achievement of, these learning goals within the classroom community. In order for this to happen, Sister Gertrude institutes practices that require students to express their ideas, to attend to the ideas of others, to negotiate with others the status of their respective ideas by exploring the bases and implications of those ideas on intellectual grounds, and to come to agreement as a whole class or in smaller groups about which ideas are the most effective on grounds of consistency, generalizability, and explanatory power. That Sister Gertrude regards these practices as critically important is clearly demonstrated by the amount of time devoted to them. These are community practices that lead to the social construction of accepted understandings of the key ideas of the unit. Since we find it impossible to separate the attainment of the learning goals by individual students from the classroom activities that facilitated their attainment, this is best described in Cobb's (in press) terms as a reflexive relationship between the social and the psychological. To put it another way, Sister requires her students to demonstrate their competence "through their involvement in the activities of the culture" (Driver, et al., 1994, p. 7).

Each of the learning goals also requires sophisticated metacognitive thinking on the part of the learner. Sister Gertrude's instruction facilitated and supported an intellectual environment in which metacognition could take place. The students, for their part, were charged with the metacognitive tasks of recognizing the limitations of their ideas and deciding if their current ideas were sufficient to explain phenomena or were in need to change. As before, there is a reflexive relationship between the psychological task of being metacognitive, the social nature of the intellectual environment that facilitates development of these skills, and the negotiation of meaning for science concepts.

Presentation and analysis of data

Data for this study included field notes of instruction, video tape of classroom interactions, and personal communications with the teacher. These data were collected over a period of two academic years in grades four, five, and six. Data excerpts are presented below to highlight the instructional practices of Sister Gertrude that supported and facilitated the ability of students to reflect on ideas. Excerpts of classroom discourse were selected to illustrate two types of learning outcomes that occurred for students in this classroom—learning that resulted in the students' ability to apply status constructs during science discourse and learning that resulted in adopting some of the epistemological commitments of the scientific community.

Sister's instructional goals

Table 1 contains the learning goals Sister Gertrude presented to her students. Collectively, these goals established the conditions under which students were expected to learn science. Proposed by Sister Gertrude, these goals sent a very clear message to students that the curriculum in this science class would be their developing ideas and that they would be expected to speak about their ideas in "scientific ways." How Sister Gertrude communicated each learning goal to the students is presented below. Each of the goals, if achieved, would give the learner awareness of and control over his or her thoughts about the science content they studied. Although none of the learning goals specifically addresses science content, together they provide students with insights into the construction of knowledge, their own and that of the scientific community. Our analysis of Sister's presentation of these learning goals highlights the implications each had for establishing a community of discourse within the classroom. This analysis, of course, does not imply that students had achieved these learning goals: that evidence is presented later.

Learning goals one and two, the recognition by students that they have ideas and that they are somehow attracted to those ideas, are not trivial matters. Awareness of the fact that you do have ideas and that those ideas guide your thinking is a fundamental act of metacognition. If

students are to gain control over their thought processes (e.g., become metacognitive) they need to express their current thoughts about a topic. Teachers, of course, can also make use of information elicited from students to plan their instruction, as will be shown later, but it is the individual student who needs to have a meta-level of awareness. Very early in her instruction, Sister Gertrude brought out her expectation that each student would speak about his or her ideas with statements like the following:

Sister: Do you have ideas? Can you talk about them? Bring them out into the open. Why do you like your ideas? Why you're attracted to them?

While many teachers have elicited students' propositional ideas when teaching (Hewson & Hewson, 1988), few emphasize the need for students to talk about why they are attracted to those ideas. In effect, students in Sister's classroom were being asked not just to state their ideas but to value those ideas as their way of understanding how the natural world works. Statements like the one above were very common early in the school year, when Sister established the climate within which ideas would be discussed in this classroom. However, similar statements appeared periodically throughout the year, frequently in conjunction with comments about other learning goals. In the following excerpt, Sister reminds students that their ideas will become the focus of the curriculum, to the point of driving her evaluation of the students. That students' ideas needed to be talked about in particular ways and that she would assess their ability to do so is evident in the following excerpt.

Sister: We're just going on where ever we left off on the work, not changing the kind of work we've been doing. OK? Some of the basic same things that I said to you at the beginning of the school year [still apply]. What I would be looking for as far as your grades for your report card and things are concerned in class. They haven't changed any so it's the same old stuff all right? So the next eight weeks we'll still be looking basically at the same things—do you have ideas, can you talk about them, bring them out into the open, why do you like your ideas, why you're attracted to them? You know, the what [are your ideas] as opposed to the why's [behind your ideas]. Are you consistent about what you believe? Many of you have come to the conclusion over the past three or four or five years that your ideas do have some limits and that they do change over time. That's OK. We'll try to use some physical models and things to help explain your ideas. As the school year moves on we'll add more things to that list [of learning goals].

In spite of the highly verbal nature of many of the learning goals, Sister recognized a limitation in how students might be able to express their conceptions. She offered students the option of using physical models to help them think about (and express) their ideas non-verbally. Especially in the beginning stages of learning, students may not have the ability to speak eloquently about their ideas. Physical models and drawings were frequently used by the students when they had difficulty expressing ideas verbally. The negotiating of meanings contained in both verbal and non-verbal forms of communication was evident throughout all of the activities these students were asked to do. Sister modeled this process for the students at first but later she asked whomever was speaking to clarify the idea he or she was presenting, as will be shown later.

A characteristic of Sister's instruction described earlier in this article was that she asked students to participate in constructing group lists containing words that reflected their ideas. Sister assessed information contained on these lists when planning her instruction as will be illustrated in the following excerpt. In this particular case, the students were discussing how objects move and had produced a list of words and objects placed in the categories of speeding up, slowing down, not moving, and steady pace (i.e., constant velocity). Reacting to this list, Sister determined that the students had "gone as far as they could go" in describing the motions of objects and she introduced the scientists' conception of natural motion. In the comments that follow, she asks the students to compare their ideas regarding motions to those of the scientific community.

Sister: OK, anything else you want to add to that list? So does that sort of remind you where you were last week? OK, again these [statements on the list] are dealing with your ideas. Then we went over here and said "OK, what about, you know, trying to take your ideas and compare them against somebody else's' all right?" So you've got this community of people out there and we're trying to take a look at what, you know, what do they say about the same kinds of problems? That's about where we left off, sort of ran out of time on Friday. I think we sort of started out by saying, well, that question's been around a long time—if you really could [remove all external forces from an object], how do objects behave if they don't interact with their surroundings? That's been a question that people tried to work on for a very, very long time, several thousands of years. I guess probably the one thing that's important is that people tried to build ideas just like you did. I mean you sat down here and you spent some time thinking about talking about

communicating back and forth. And all through history people have done that. Spent an awful lot of time taking a look at what they think and why they think it, and can they put it into some kind of explanation called a theory. But do you think every single theory out there has been just absolutely perfect? You're shaking your head no, why?

Notable in this excerpt is the recognition by Sister that students are dealing with an historically significant issue in the study of force and motion—how objects would behave in the absence of external forces. Sister also recognized the difficulties both her students and the scientific community have had in trying to generate theories that explain the motion of objects influenced by external forces and in the absence of all forces. The emphasis Sister placed on students understanding their ideas, and then comparing them to the ideas of others, models similar kinds of discussions that take place in the scientific community. Sister supports the efforts of her students to consider the ideas of others, and the implications that these ideas might have for their own thoughts about a topic. A desirable consequence of this practice is that, if students adopted effective ways of reflecting on the ideas of others, they would gain considerable control over their thought processes. Learning goal four, recognition of the limits of your ideas and the possibility they might need to change, speaks directly to the issue of gaining control over thoughts.

Sister: I mean we start and take a look at your ideas and then we take a look at other people's ideas. And sometimes you find out they're the same, sometimes they're different. Then what do you do about it? I mean we've got two different ideas right here. If you like, there's only two. You know this one as opposed to this one. Are they both right or are they both wrong? Is one a little bit closer explanation of what's going on? I think that's what science has been about all along, trying to you know take a look at how do you distinguish between an idea that's pretty close to describing what's going on and maybe an idea that's way off? And it's not taking you any place. For example, this group over here spent a lot of time trying to make the difference between two different ideas and maybe that was an important thing to do because once you separated those two ideas out you could say I could use this [idea] for this [situation] and [another idea] for that [situation]. But then the more you talked you found that you really couldn't separate those and kept switching back and forth and end up talking about the same thing. You don't know so you have to try it right? To see if you really have two different things here. So sometimes you know taking your own ideas, and taking a look at them, see where you start and then comparing against somebody else's. We did that with Aristotle last week remember? We said that he had this idea that the earth didn't move?

<Student's: yeah> OK, well from our Twentieth Century perspective we've been in outer space. You know, we live in a time and age when people have actually been out there and there's no way I don't think anybody except maybe somebody very very young would say that the earth doesn't move. It's just not something we buy into. Well when this person

lived a long time ago that was the best explanation he could come up with <Bruce: that it didn't move?>. That the earth didn't move. And now when he spent a lot of time thinking about that, and perhaps he was trying to say "well what are the implications of a moving earth?" But that idea stayed around for 2,000 years or more before anybody else challenged it. It wasn't until you got down to maybe people like Galileo or Isaac Newton who lived in the Fifteenth Century . Newton specifically was able to challenge some of these ideas to say we know that was good then but is it still good now? Maybe this is good for fifth graders but is it a good explanation for what's really going on out there? Now how do you find out what's a good explanation? . . . [If an idea] can be used here and here and here, and you can just find lots and lots of places where it seems to apply, maybe it's a pretty good idea.

Apparent in the excerpt above is the recognition by Sister that ideas within the scientific community had changed over time, for good reasons, and that many of the students had also changed their ideas when they realized the limitations of those idea. Then, having made the point about the need to compare different explanations, Sister raises the question of criteria for choosing between different explanations and suggests one: good ideas can be applied in many places, i.e., they are generalizable. Her intent is that this should become a norm of classroom practice. Since generalizability is closely related to consistency (Hewson & Hewson, 1984), this point leads directly into the third learning goal.

The need for consistency of thought, the third learning goal, is addressed in the next excerpt. By consistency, Sister meant that similar phenomena should have similar explanations. In the instance below, consistency had to do with whether gravity would effect a marking pen dropped at two different locations in the room equally. All of the students agreed that the marker would fall to the floor in both places, and that gravity caused the marker to fall. Sister used this simple demonstration, that everyone agreed represented the same phenomenon, as an example of applying a consistent explanation to similar events.

Sister: OK, the situation hasn't changed. So, if the situation hasn't changed, the explanation hasn't changed, all right? . . . One of the things we just sort of saying is if you've got the same situation you might want to look for the same explanation, OK? If you have a different situation you may have to look for different explanations, OK? So let's just concentrate on the same situations, same explanations, all right? I'm going to let this marker go. Pete what's going to happen here?

The development of learning goals six and seven, status constructs for intelligible and plausible, followed a sequence of instruction similar to that for other topics. A full description

of the events that led to the students' definitions for intelligible and plausible can be found in Beeth (1993) and will not be repeated here. What is presented here is the rationale Sister used to explain why the students should define and then apply these terms to their science ideas.

Sister: We're trying to use some words that will help you explain your ideas a little bit better because if you have ever tried to talk about something and you find out "I can't say it . it doesn't come out the way I want it to..." So I think we're using intelligible, plausible, fruitful just as a little bit more powerful way of trying to talk about your ideas. It takes a little bit of time to develop that power.

and

Sister: Some ideas why you think they're intelligible or unintelligible. On this line [reading from student posters] can't understand it, doesn't make sense, can't picture it, doesn't give [me] an idea. So it seems like most of the things that you were trying to answer on that little quiz is, to be intelligible you have to understand the words and then the words have to convey an idea. That seemed to be coming out on almost all of them. Do you feel comfortable with that?

The learning environment Sister Gertrude sought to create was unique in many respects. Guided by the vision of learning embodied in her learning goals, she expected her students to discuss their ideas, speak about the reasons for their ideas, and recognize when an idea needed to change. Discussion of ideas of this order is similar to the kinds of discussion engaged in by the scientific community. Pedagogically, Sister Gertrude set a task for students to consider the depth and breadth of their developing ideas regarding a topic.

Having explored science learning at this metacognitive level, Sister then introduced the students to significant conceptual problems in a topic. Sister's patience in introducing students to ideas other than their own (e.g., ideas of the scientific community) is a remarkable trait of her instruction. Her decision to do so was always based on the thoughts and ideas expressed by her students and reflects her understanding of how ideas are discussed in the scientific community. Students learning science in this classroom were not expected to merely repeat the propositional statements of canonical science, they were expected to engage in the kinds of discourse that Sister thought modeled scientific thinking. While it was possible that students might have ideas about natural phenomena following instruction that differed from canonical science, they would have developed well-constructed arguments for why they had chosen them

over accepted ideas. How students exposed to Sister Gertrudè's learning goals responded to her instruction is presented in the section that follows.

Student responses to Sister's instruction

Although the learning goals Sister presented to her students appeared in the form of an ordered list, the students did not experience or apply them in the same sequence. Some learning goals, such as the status language, were taught explicitly by Sister Gertrude (see Beeth, 1993) while others were applied as constructs when discussing science content. Three sequences of classroom discourse are presented below to highlight the influences of these learning goals in Sister Gertrude's instruction and the students' abilities to reflect upon their own ideas or those of others. In the first exchange below, Sister Gertrude works with the students to investigate what they know about a science topic—force and motion. The second sequence illustrates the co-construction of a metacognitive environment among a small group of students and a teacher/researcher working under the direction of Sister Gertrude (MEB). The final sequence of discourse illustrates the students' abilities to apply several learning goals among themselves as they discuss science content.

The first sequence of discourse presented below involves negotiating the status (i.e., initial intelligibility) of the idea that an inanimate object can exert a force. Sister Gertrude's instruction at this time is directed to individual students and the sense they can make out of this idea. During whole class instruction, Sister Gertrude presented the students with a handout containing six different illustrations of forces acting on the book. The illustrations of forces acting on books depicted no force, multiple forces coming from all directions, one downward force, two balanced forces—equal and opposite in magnitude, and two illustrations showing unbalanced forces, one with a larger downward force, the other with a larger upward force. The illustrations represented ideas Sister had gleaned from the science education research literature and her experiences teaching science in the elementary school. At this point in the instruction, students had chosen the illustration that best represented their current thinking

about forces acting on the book. None of the students choose two equal and opposite forces as the explanation.

That none of the students choose equal and opposite forces as the explanation was expected by Sister (Hennessey, personal communication). From the students' perspectives, how could an inanimate object, like a table, exert a force? She knew that her instruction needed to facilitate a discussion that established the intelligibility of this idea for students if they were to learn anything more about force and motion. Students were asked to consider the idea that tables might be able to exert force. When reading the exchange below, note that Sister asked the students what they might need to know about forces, rather than just what they did know. Although not represented here, she had already determined, by the selection of an illustration that represented their thinking, the propositional knowledge these students have about forces acting on an object at rest. What she wanted to know was what meaning these students were making from the arrows used in the illustrations. The arrows represented forces, and these forces had to come from somewhere. Although the students were probably not aware of this logical consequence, Sister knew that regardless of which illustration they choose, a student would need to justify where those forces could come from.

Sister: What would need to know in order to find out what's a better explanation? You know, what are some of the things you might need to know?

Rob: What those arrows mean.

Sister: OK. So we need to know something about arrows.

Bruce : What you are going to let them [the arrows] stand for.

Sister: OK. So about the arrows. What other things would you need to know besides arrows.

Kirsty: You would have to know like what each picture is telling you.

Sister: OK. You've got some pictures here that are trying to say something. You need to interpret the pictures I guess.

Mr. Beeth: Do you need to know anything about books?

Rick: Well maybe. You've got to know if they will go off and float or something but we already know that they won't.

Kirsty: Well maybe you have to know the weight.

Student: Force.

Sister: As Mr. Beeth said, do you need to know anything about books? Do you need to know anything about tables?

Students: [some say No, some say Yes]

Sister: That's about the only thing you are dealing with.

Rob: Do they [exert a] force?

Sister: So in one sense that is pretty important. What about books? What about tables? What do you know about them? If you sort of refuse to consider them you're probably not going to get very far because that's all you are really dealing with is the table and the book. And what do these arrows stand for? There isn't anything else in this picture.

The discourse above focuses on negotiating the meaning of arrows used as a representation for a force. Among the conceptual knowledge embedded in the illustrations of books and tables are assumptions about the source of any force represented by an arrow, not just how many arrows there are. The students had focused their attention mainly on the number of forces, for the most part preferring one force rather than two. However, Sister indicated (in personal communication) that no matter which illustration of force a student chose, they would need to justify how that force came about. Sister accepted gravity as an explanation for the downward pointing arrow and 'air pressure' for the illustration showing multiple arrows pointing toward the book. However, she asked the students to consider the source of any upward pointing arrow. At the end of this exchange between students and teacher it is likely the students had become aware of the consequences their choice of an illustration had in terms of explaining the forces acting on the book. While it can not be said at this point that these students adopted equal and opposite forces as an explanation, it is clear that they knew that any explanation of forces acting on the book needed to contain an explanation of where those forces came from.

The students focused their comments exclusively on propositional information about the arrows shown in the illustrations. Sister, however, recognized a logical problem that must

emerge for these students, what do these arrows imply about the origin of a force indicated by an arrow? Her instruction facilitated discussion of the students' ideas and then confronted them with the limitations of the idea they were proposing. It is notable that Sister Gertrude did not tell the students which illustration was correct, only that they might need to consider the consequences of their choice. In other words, an expectation had been established in the classroom that simply connecting a symbol (a force arrow) to an object (table) was insufficient, i.e., the expected practice of the class was that a physical explanation of the connection was required.

The next sequence of discourse occurred within the same series of lessons on force and motion. A statement from the above excerpt, "Do you need to know anything about tables?", is addressed by Sister in this instruction. She planned to confront her students ideas regarding the passive nature of tables. By this point in her instruction, all of the students agreed that gravity was the only force acting on the book, and that the table acted only to block the path the book would take if the table were not there. The students idea was illustrated by a single arrow, representing gravity, pointing at the top of the book. All students agreed that this explanation of the force(s) acting on the book was both intelligible and plausible. Recognizing that the students "could go no further with their idea" Sister asked if the table could be exerting a force on the book. She attempted to demonstrate this through an analogy to a book placed on the out stretched hand of a student who clearly needed to exert a force in opposition to gravity; similarly the table would have to exert a force to support a book. The students admitted that a force in opposition to the force of gravity was needed to support the book. When asked to reconcile these two events, the students consistently rejected the analogy. At this point, Sister asked the students to form small groups to discuss the possibility that the table could, in fact, exert a force. She used two arrows of equal length, pointing in the opposite directions, to illustrate the idea she proposed.

The essence of Sister's suggestion that a table might exert a force was two fold. First, could the students find the idea that a table exerts an upward force on a book intelligible, and

second, what are the implications for your ideas of thinking that a table could do this? The conversations that follow occurred among one author of this article (MEB) and a small group of students.

Mr. Beeth: What we're trying to deal with is, can the table do anything to the book?

Students: Nope [said with conviction].

Mr. Beeth: It can hold it up, OK? So is that like an act? Is it doing something to the book?

Students: No.

Rick: But they [students not in the group] were saying it's a force though. They're saying it with the arrow. They're saying it's a force going upward with the arrow and I'm saying anything that's [pointed] up is [moving] up.

Mr. Beeth: Do we want to think about this as a force or not? I mean, it is holding the book up right? You can agree on that right? The book isn't able to fall through the table but is what it's doing to the book, do we want to think about that being a force?

Rob: What is the table [doing]? If we said the table was a force then everything would have to be a force

Mr. Beeth: What else would have to be a force?

Rob: The computer [sitting on the table] everything in this room.

Rick: Yes, everything on the table, everything in the room, would have to be a force then.

Mr. Beeth: OK. Is it impossible to think that way?

Students: No.

Rob: If you said the table is a force because it holds something up, the pencil can hold something up, the computer can hold something up.

Mr. Beeth: OK. So if I put this pencil on the computer?

Rob: It's holding it up.

Jake: Force [implying that the computer does exert a force on the pencil].

Mr. Beeth: Can we say that the computer is acting on the pencil?

Jake: Yes [said with conviction]!

Rob: No [said with equal conviction]!

Students: [opposing Rob's objection].

Rob: Why?

Jake: Well, because it is holding it up.

Mr. Beeth: OK. What if we say that there is no force holding it up. That the computer is just in the way or the table is just in the way? You like that idea better?

Kim: There was no force holding it up.

Mr. Beeth: Who likes that idea? Kim's not sure. OK, Jake what do you think about that?

Student: If there's no force holding it up the table was just in the way.

Jake: Yeah. The table is just in the way. The in-the-wayness [sic] is a force. It's blocking it.

Mr. Beeth: It's blocking it?

Jake: Yeah, blocking it from dropping.

Mr. Beeth: So you're saying it is like a force, right Jake?

Jake: Yes.

Rick: Well you said it would be going down and there would be no forces or like what did you just say? Like could you all agree on that?

Mr. Beeth: Well, we're trying to decide if the table is doing something to the book, and the pencil, and the computer but do we want to think about that as being a force? You say no?

Rick: Wait!

Pete: What kind of force would it be?

Rob: Yeah, what force would be applied to it?

Mr. Beeth: Is it like a push?

Rob: Yes, or is it like a pull down?

Jake: Just like Pete [in the demonstration], every time we put another book on [his out stretched hand] he had to push up harder to keep it level. And that thing [the table] pushes it [the book].

Don: So you're saying this [table] pushes harder?

Jake: No but eventually if you put enough stuff on there it will break because it's not human.

Rick: So whatever is not human breaks if you put ...

Jake: If you put like if you put like a five million ton thing on this [table].

Mr. Beeth: Right. If you put something real heavy [on the table it would break].

Rick: Yeah.

Jake: Yeah. If you put something real heavy on it.

Rob: But we're saying a pencil or the book.

Mr. Beeth: OK. So you're saying [the table] is like a force, right Jake?

Jake: Yeah.

Rick: Well you said it would be going down and there would be no forces or like what did you just say? Like could you all agree on that?

Mr. Beeth: Well, we're trying to decide if the table is doing something to the book and the pencil and the computer but do we want to think about that as being a force? You say no?

Rick: Wait.

Pete: What kind of force would it be?

Rob: Yeah. What force would be applied to it?

The conversations represented immediately above are, first and foremost, about a significant conceptual problem many students experience when learning physics—the ability of inanimate objects to exert a force. Understanding Newtonian physics depends on learning why physicists have adopted this concept. Sister's instruction asked the students to discuss the consequences of the Newtonian idea, an idea that none of them found plausible. This is different than the previous example in which students were asked to consider the limits of their ideas about tables and books. In effect, she is asking the students to reason abductively (e.g., If I think that tables can exert a force, then ...) as is common in many debates within the scientific community. In the exchange above, it is clear that the students did engage in this kind of reasoning.

Throughout the sequence of the conversation above, the emphasis shifted from negotiating the intelligibility of a scientific idea to discussing the kind of force a table would exert, if it

could. Students in this small group rejected the initial idea as unintelligible until Jake stated that the “in-the-wayness” of the table was a force. It is Jake who convinced his peers that it was possible to think about inanimate objects as capable of exerting force, even if you might not know how they can do this. Once this idea became intelligible, the conversation shifted to the implications of accepting this idea. If tables could produce force, than other inanimate objects in the room must also produce forces. The generalization of this idea to cover all object was unsettling for Rob, and, in deed, he indicated his opposition to this idea early in the discussion.

While it should not be concluded from these statements that the students accepted a Newtonian point of view, the fact that they engaged in a discussion about the consequences of adopting a Newtonian perspective are remarkable. Rick’s statement, “Yes, everything on the table, everything in the room, would have to be a force then”, is indicative of a shift in the group’s idea away from the emphatic belief that ‘tables can’t push’ to a more hypothetical position. The fact that Rick was exploring the implications of the idea by attempting to generalize it and was immediately able to participate in the exploration is evidence that this scientific norm had become an accepted practice in the group.

The discourse presented above is metacognitive in that students were deeply engaged in talking about ideas other than their own. Once they found the “alternative” (i.e., Newtonian) idea intelligible, the focus of their discussion turned to the consequences of an object that, now, could possibly exert force. Recognizing the implications of ideas other than your own is an act of metacognition in the sense that you must reconcile the discrepant idea with your own. Also noteworthy in the exchange of ideas presented above is the fact that the bulk of the conversation occurred among students. After explaining the task in the small group, the researcher intervenes only to clarify statements made by others. These students exhibited the ability to have sustained and profound discussions about science content, applying the intellectual tools Sister Gertrude helped establish through instruction of the learning goals. In doing so, they were indeed “involve[d] in the activities of the culture” (Driver, et al., 1994, p.7)

The final exchange presented here illustrates the ability of students in Sister Gertrude's classroom to engage in discussing their ideas with minimal intervention by the teacher. In the discussion that follows, several students discuss Kirsty's inconsistent ideas regarding the forces acting on a mass suspended by a spring. Throughout this conversation the other students in the class support Kirsty as she comes to realize that the explanation of forces for a book at rest on a table is the same as that for a mass suspended by a spring.

Kirsty: OK, gravity is pulling on the weight but then the spring is pulling back. Well gravity has a greater magnitude than this spring.

Pete: Why do you think that? Because if there was like Bruce said, that there's more gravity on the weight, wouldn't it [stretch out] because gravity is a puller [sic] and it pulls [down]. And this spring didn't [stretch]. If the spring and the ribbon didn't hold it up at the bar it would hit the desktop if there was more gravity.

Kirsty: I think I have these arrows mixed up. Are you trying to say that since there is more gravity, it would be pulling the weight and the weight would be going down right?

Pete: Yeah.

Mr. Beeth: Does that make sense to you Kirsty?

Kirsty: Yeah. I think I got the arrows mixed up.

Kim: I have a question for Pete. Well you know gravity I think it only pulls down when it has like the amount that it has to and then like it's if something is like holding it from like going down to the ground I think or going where it wants to I think it would like go up again.

Pete: Yeah. Well then the spring would have to have a greater magnitude on it.

Kim: No, because see when you pull it down it like stretches out you know?

Pete: Yeah.

Mr. Beeth: So Kirsty, do you want to change your arrows now and have a big arrow pointing up and a small arrow pointing down?

Kirsty: Yeah. Because if there's more gravity the weight would just like pull down.

Mr. Beeth: OK.

Kirsty: And then since the spring's magnitude is like smaller then the weight it would just go right down.

Mr. Beeth: OK.

Kirsty: Jake?

Jake: Well, if the magnitude was greater up it would go like that [motions upward].

Nancy: Even if it was suspended?

Jake: Even if it was suspended. I mean if there is a greater magnitude from this [spring] it would go up. It's at rest.

Kirsty: No.

Jake: Yes. Just like the book on the table. It's at rest, there should be equal forces.

Bruce: Yeah, they should be equal.

Jake: Yeah, it's consistent.

Mr. Beeth: Why do you like that idea better than the others?

Kirsty: Well because I really didn't think of it as at rest. I was just thinking of it as suspended. I really didn't think about that so I wasn't really looking at if it was at rest or not.

Pete: You weren't thinking of at rest right?

Kirsty: No.

Sister: How would you [explain] this [suspended pendulum]?

Kirsty: That?

Sister: Yes.

Kirsty: Probably like the suspended weight.

Sister: Draw it on the board. How would you label it?

Kirsty: Can I just draw a dot [to represent the pendulum]?

Sister: Sure.

Mr. Beeth: What are you thinking about?

Kirsty: Well I'm thinking about if like gravity has a really great like magnitude then . . .

Mr. Beeth: If gravity has a greater magnitude than the string?

Sister: Can you tell me what you drew?

Kirsty: Those arrows are supposed to be equal, OK? Because it's supposed to be like suspended right?

Sister: I'm asking you.

Kirsty: Well I think it's at rest.

Sister: You think it's at rest?

Kirsty: That's why I put the arrows equal.

This conversation between Kirsty and the rest of the class is extraordinary in a number of ways. First, Kirsty communicates her ideas about the forces acting on the spring in a clear and concise manner. Other students in the class do the same and reveal that they have different explanations for the suspended weight than Kirsty. Second, these students understand both Kirsty's idea and their own well enough to lead her through a series of interactions that help her to recognize that the book on the table and the suspended mass are similar phenomena, thus requiring similar explanations. Kirsty is then able to apply her new conception to the example of the suspended pendulum provided by Sister Gertrude. The supportive nature of this classroom practice is remarkable. Third, the teacher and researcher interrupt the students' discussion only to clarify minor points or extend the conversation to a new example. In this instance, students demonstrate their ability to speak about science conceptions in powerful ways, ways that allow them to monitor and control their own learning.

It is clear that these students are individually exploring the status of important science concepts. It is equally as clear that the intellectual and social environment of the classroom is essential for their learning. Some norms that guide the class are a) respect one another's point of view, b) it is acceptable to question other students about their ideas, and c) the way to convince someone else is to use arguments about the science content (rather than referring to authorities or exerting social pressure).

Conclusions

In this article our goal has been to address the research question: How does a teacher support and facilitate conceptual change in students' thinking? Prior to addressing this question, we considered the multiple meanings for *conceptual change* that are necessary to

understand the conceptual change learning of science content: these focus on learning about learning and about scientific epistemology as well as learning science content. The primary implication of this discussion is that much of the learning students in this classroom needed to experience involved the development of their ability to engage in discourse of the kind practiced by the scientific community. To address the question, we described and analyzed Sister Gertrude's instruction in light of these multiple meanings, using her own words and students' responses to her instruction as the primary sources of data. In this section we summarize the key elements of Sister Gertrude's instruction as illustrated in the previous section and discuss their implications.

The key elements of instruction that support and facilitate conceptual change in students' thinking are:

1. The teacher designs her curriculum. This means that she chooses the central concepts of each unit, decides the questions that are the particular focus of the unit, and plans the range of phenomena that students will experience. In other words, she takes it as her responsibility to clarify the space--physically, conceptually, and socially--in which her students will be working.
2. The teacher includes parallel strands in the curriculum. These strands match the different meanings of conceptual change outlined earlier, i.e., she intends students' learning outcomes to include conceptions of science (both propositional and procedural), learning, and scientific epistemology. The latter two are encapsulated in her learning goals.
3. The teacher makes her curricular expectations known to the students in a variety of ways: through explicit instruction, through the provision of carefully chosen experiences, through input from her students and other sources, and through constant modeling of the activities and practices inherent in her learning goals.
4. The teacher uses instructional strategies to facilitate students' exploration of their own and others' ideas through individual, small group, and whole class activities. In doing so, she

monitors the process by which this happens and intervenes when there are departures from her learning goals. She does not intervene with respect to science content, however, until students have “gone as far as they can go” in discussing their ideas. At these times, she confronts students with ideas other than their own, challenges them to think about a world in which the new idea might be true, and engages them in building consensus between groups of students, if not the whole class. The teacher’s instruction responds not only to the ideas about science content that students are learning but how well her students are able to reflect upon those ideas.

5. The teacher allows time for students to engage fully in the social and conceptual practices that she believes are necessary for students to achieve her learning goals.

Discussion

These various aspects of Sister Gertrude’s instruction serve to clarify that she plays different roles. Some of these are proactive and are an essential part of setting the stage for what subsequently transpires in her classroom. Her instruction facilitates individually accountability by asking each student to comment on their ideas in various ways and at the same time confronts students with the task of generating a shared epistemology. Having set the class in motion, she monitors students’ actions and, where necessary, reacts to classroom events in order to facilitate progress in the direction she has planned.

One caveat in summarizing Sister Gertrude’s instruction is that we are conscious that it is very easy to focus on sections of dialogue in which her students are discussing significant issues among themselves with minimal participation by the teacher. It is possible to dismiss the wider applicability of these learning outcomes on the grounds that these students are doing it for themselves and thus are unlike typical students elsewhere, or that Sister Gertrude’s unique personality (that cannot be duplicated elsewhere) is responsible for this learning. On the contrary, our intent is a) to argue that there are instructional practices that are essential if students are to achieve these outcomes, and b) to express our belief that other teachers can use these practices to create classrooms in which similar student outcomes are achieved.

In portraying Sister Gertrude's instruction as a series of practices, we do not imply that the order in which they are discussed dictates a sequence for instruction. We recognize that there are good reasons why it makes sense that some activities may occur before others, but that the sequence of instruction is the responsibility of each teacher and is dependent on the response of students to that instruction. Perhaps the most important characteristic of Sister Gertrude's instruction is that it continually changes in response to the ideas expressed by her students.

Sister Gertrude's instruction, framed by her learning goals, supported students as they learned how to learn science content. Through her instruction, Sister facilitated a metacognitive learning environment that enhanced her students' efforts to speak about their ideas, offer justifications for those ideas, recognize the limitations of an idea, and negotiate the status of ideas. Although Sister Gertrude used students' ideas as the basis of her curriculum, she also addressed some of the most difficult conceptual issues for a topic and the epistemology of science. Her instruction consistently set learning tasks that focused on a student's ability to speak about their ideas in scientific ways. Although Sister Gertrude did insist on the nature of discourse in this classroom, she did not assume that her instruction would result in each student adopting contemporary views of science.

The fact that students in Sister's classroom exhibited the ability to engage in discourse like she believed occurred in the scientific community is also noteworthy. In the end, these students did exhibit changes in the amount of propositional and relational knowledge they held about force and motion. However, students in Sister's classroom also showed changes in their abilities to remain engaged in discussion of scientific ideas. Sister's instruction led to a depth of introspection into your own ideas (e.g., determine status, recognize limitations, and change your thinking when necessary) and an openness to the inherent possibilities in alternative ideas that is essential to conceptual change learning. These changes, in what it means to learn science, provided her students with significant insights into the epistemology of science. They also

helped her students learn significant aspects of social knowledge construction like those Driver et al. (1994) suggested are needed in science learning.

Much of the interactions that occurred among teacher and students in this classroom can be characterized by Cobb's (in press) notion of reflexivity. Although none of the students learned science by themselves, each needed to develop individual abilities such as determining the status of ideas and speaking about the reasons he or she believed most significant regarding a topic. These aspects of thought can not exist apart from the individual. On the other hand, the social environment generated among teacher and students, and, perhaps more importantly in this case, between students, was especially significant to the learning that did occur. The teacher consistently asked her students to think more deeply and provide more information in support of the ideas they expressed. This seemingly simple act of speaking about ideas became the foundation for negotiating understanding. The degree to which students in this classroom began to negotiate understanding with one another and to help one another think through their ideas on their own is a hallmark of Sister Gertrude's instruction. As her explicit directions to the students diminished, the students' voices get stronger, more authoritative, and more insightful. Students in this classroom learned science content by creating a community of discourse similar to that of the science community. In a very real sense, students in this classroom became metacognitive as a result of the teacher's instruction, taking greater control over the responsibility for their learning than is typically expected of most students.

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