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RESEARCH REPORT

'That's what scientists have to do': preservice elementary teachers' conceptions of the nature of science during a moon investigation

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In a science methods course for elementary education majors, students investigated the phases of the moon for six weeks. The moon investigation emphasized that scientific knowledge: a) is empirically based; b) involves the invention of explanations; and c) is socially embedded. After the moon investigation, students realized that scientists make observations and generate patterns, but failed to recognize that observation could precede or follow theory building. Students could separate the processes of observing from creating explanations in their learning, but did not articulate the role of invention in science. Similarly, students valued the social dimensions of learning, but were unable to apply them to the activity of scientists. Although our teaching was explicit about students' science learning, we did not help them make direct connections between their science learning activities and the nature of science [NOS]. We provide a set of recommendations for making the NOS more explicit in the moon investigation.

Introduction

In the US, the National Science Education Standards [NSES] (National Research Council 1996) set standards for teacher knowledge of science and of science teaching. According to the standards, knowledge of science includes knowledge of science concepts and principles as well as knowledge about the nature of science [NOS]. As stated in the NSES:

> All teachers of science must have a strong, broad base of scientific knowledge extensive enough for them to understand the nature of scientific inquiry, its central role in science, and how to use the skills and processes of scientific inquiry.
>
> (p. 59)

Although strong agreement about NOS knowledge goals for teachers exists in the science education community, research about teacher understanding of the NOS is not very encouraging (Lederman 1992). We know, for example, that future elementary teachers lack clear images of the NOS when they enter science teaching courses (Abell and Smith 1994, Bloom 1989). We believe that their naïve realist views of science have been developed during their years in the apprenticeship of observation

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(Lortie 1975). Throughout their school careers, they have witnessed a didactic orientation to science instruction (Anderson and Smith 1987) where science is presented as a body of static knowledge, or what Schwab (1960) called rhetoric of conclusions. We also believe that views of the NOS are tied to prospective teachers' beliefs about science teaching and learning. Students of teaching 'see science as a process of discovering what is out there, not as a human process of inventing explanations that work. Likewise they see learning as a process of acquiring knowledge through discovery' (Abell and Smith 1994: 484).

Yet the question of how best to prepare teachers to understand the NOS is still open to discussion (Abd-El-Khalick *et al.* 1998). Although there is a growing collection of resources for teaching the NOS to teachers (for example, Cobern 1991, Loving 1991, Lederman and Abd-El-Khalick 1998) science teacher educators are a long way from having a shared set of assumptions and goals that incorporate the NOS into science teacher education. This study is an attempt to contribute to such a body of knowledge by examining what happens when teacher educators model scientific activity and science talk (see Lemke 1990, Reddy *et al.* 1998) as well as discuss epistemological features of science with preservice elementary teachers in the context of a science methods course.

Background

We teach a science methods course to future elementary teachers. The course has been designed using a reflection orientation (Abell and Bryan 1997) that provides opportunities for students to build theories of science teaching and learning as they: 1) observe others teach; 2) reflect on their own teaching; 3) read expert theories; and 4) examine their own science learning. In this last context, students engage in a six-week investigation of the phases of the moon (Duckworth 1987, van Zee 2000) where they make observations, keep records of their sightings, participate in large group data sharing, solve problems in small groups, and maintain a journal of their learning experiences. This project occupies a major part of the first third of the course; the moon journal assignment accounts for 15% of the final course grade.

One of the goals of the moon investigation is to help students understand the phases of the moon. As others have documented and our experience supports, students come to the moon investigation holding ideas about the moon's phases that are inconsistent with the scientific account (Baxter 1989, Jones *et al.* 1987, Targon 1987). During their study of the moon, our students move toward a more scientifically accurate understanding of moon phases. Second, we use the moon investigation to help students build their own theories about science teaching and learning. As we have shown elsewhere (Abell *et al.* 1996, Martini and Abell 2000), the moon investigation can be a catalyst for the development of teaching and learning theories when students compare their moon learning experience with other course activities and topics throughout the semester.

A final goal of the moon investigation is to enhance student understanding of the NOS. Lederman and his colleagues (e.g., Abd-El-Khalick *et al.* 1998) propose particular aspects of the NOS that we agree are useful to address in science teacher preparation:

> That scientific knowledge is tentative (subject to change); empirically based (based on and/or derived from observations of the natural world); subjective (theory-laden); partly the product of human inference, imagination, and creativity (involves the invention of explanation); and socially and culturally embedded. (p. 418)

These researchers, and documents such as the NSES, distinguish between these epistemological features of science and the processes used by scientists to conduct scientific inquiry (e.g., predicting, measuring, collecting data, and recording data). In our science methods course, we were interested in promoting the epistemological features of the NOS, not merely the science processes. Abd-El-Khalick *et al.* (1998) have cautioned that the NOS cannot be taught 'implicitly' by having students participate in science activities, assuming they will arrive at NOS knowledge through their participation. Instead they recommend 'explicit' attention to the NOS in science teacher education. The purpose of this study was to examine our own teaching practices for examples of explicit instruction about the NOS and examine student outcomes in terms of their understanding of the NOS.

Methods

This self-study was guided by an action research methodology, distinguished by an iterative cycle of planning, action, observation, and reflection (Hopkins 1985). Action research enables researchers to 'articulate, validate and develop their views and to design action in order to improve the situation they live in' (Altrichter 1993: 40). One member of the research team (Martini) served as a participant observer in two sections of an undergraduate science methods course for elementary education majors taught by the other two researchers (Abell and George). During a six-week period at the beginning of the semester in which the moon investigation took place, the participant observer attended all class sessions in the two sections, took field notes, and tape recorded small group discussions. Eleven students volunteered to serve as key informants in the study. Each informant kept a journal of their moon observations, their developing explanations, and reflections on their learning. Each week course instructors prompted them to write about the investigation and about particular aspects of science teaching and learning (e.g., attitudes, science talk, children's literature). Instructors also asked students to write a final reflection in which they discussed their most current explanations about the moon, the questions they still had, and their ideas for teaching about the moon in elementary school. In addition, each informant participated in a one hour post-unit interview based on a structured interview protocol (Patton 1990) conducted by Martini. This interview focused on current conceptions of phases of the moon, beliefs about science teaching and learning, and NOS understandings.

The interviews and field notes served as the primary data sources for this study, triangulated with student journals. To analyse these data, all three members of the research team independently read and reread the data set to search for common patterns, a process referred to by Goetz and LeCompte (1984) as analytic induction. In team meetings we discussed these patterns until no new patterns emerged. We also brought our own beliefs about science teacher education and the NOS to these meetings, using them to focus and extend the data discussions. Next, we analysed the data set according to features of the NOS described by Abd-El-Khalick *et al.* (1998) and the National Science Education Standards (1996). We chose the NOS features that we considered most appropriate to the moon inves-

Table 1. Features of the nos. used to analyse the moon investigation.

Features from the NOS in teacher education literature (Abd-El-Khalick *et al.* 1998: 418)	Corresponding Description in the National Science Education Standards Grades 5-8 (National Research Council 1996: 171)
• Scientific knowledge is empirically based (based on and/or derived from observations of the natural world). • Scientific knowledge is subjective (theory-laden).	• Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models . . . For most major ideas in science, there is much experimental and observational confirmation. . . Scientists do and have changed their ideas about nature when they encounter new experimental evidence that does not match their existing explanations.
• Scientific knowledge is partly the product of human inference, imagination, and creativity (involves the invention of explanation).	• Scientists formulate and test their explanations.
• Scientific knowledge is socially (and culturally) embedded.	• It is normal for scientists to differ with one another about the interpretation of the evidence or theory being considered. Different scientists might publish conflicting experimental results or might draw different conclusions form the same data. Ideally, scientists acknowledge such conflict and work towards finding evidence that will resolve their disagreement. • It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, theoretical models, and the explanations proposed by other scientists. Evaluation includes reviewing the experimental procedures, examining the evidence, identifying faulty reasoning, pointing out statements that go beyond the evidence, and suggesting alternative explanations for the same observations. Although scientists may disagree about explanations of phenomena, about interpretations of data, or about the value of rival theories, they do agree that questioning, response to criticism, and open communication are integral to the process of science. As scientific knowledge evolves, major disagreements are eventually resolved through such interactions between scientists.

tigation and to the grade level emphasized (grades 5-8). These features are described in table 1 and form the basis of the analysis of the 11 key informants that follows.

Scientific knowledge is empirically based

The moon investigation

During the moon investigation, we asked students to observe the moon each day and record their observations:

> You will watch the moon each day for the next month, making an entry in your notebook each time you make an observation. You will use your eyes and your mind to make sense of any patterns you notice and observations you make.
>
> (Course Syllabus)

Each class session began with the students sharing their data. Students recorded their data on the board in words and pictures and summarized data on a class moon calendar. Thus, the notion that science is based on and/or derived from observations of the natural world was emphasized on a daily basis throughout the moon investigation.

During the semester under study, the moon investigation began with the new moon phase; students could not see the moon over several days of observations. When students came to class saying they had 'no data', instructors emphasized that not seeing the moon was data in itself. Prompted to look for reasons why they were not seeing the moon, students generated a list of possibilities including weather, time of day, location of observer, and new moon phase. (They used the latter term without being able to explain what it meant.)

After students had collected a week's worth of data, course instructors asked them to move from recording data to organizing it and finding patterns. We asked students to, 'Describe some of the patterns you see in your journal' and 'Talk with the people in your group to come up with at least two patterns that you have noticed about the moon'. Students mentioned patterns in the changing shape of the moon, in the times it had been seen, and in the location of the moon in the sky. We also discussed the number of observations needed to claim a pattern. This led to an instructor's comment about the notion of proof in science:

> Has anybody heard about the Sun rising in the east and setting in the west? We can only prove it by looking at it every single time and that's impossible because it's infinite. But it only takes one time to disprove it.
>
> (Field Notes, week 4)

In these ways we emphasized the role of observation in science. We were interested in the extent to which students would exhibit an understanding of scientific knowledge as being empirically based by the end of the moon investigation.

Student conceptions

In post-unit interviews, participants were asked, 'In what ways do you think the moon investigation represented what science is or the things that scientists do?' In their answers, almost every key informant mentioned processes of science, including observing, collecting data, and recording data.

> Scientists have to observe . . . You can't see patterns without collecting data and observing.
>
> (Laurie, interview)

> [Science] needs some careful observations. . . recording ideas. . . Journals are what scientists do every day. . . In science one of the arts is observation and then hypothesizing and recording.
>
> (Michelle, interview)

Many students made a direct link between the activities of the moon investigation and the activities of scientists.

> I feel that [the moon investigation] represented [science] in several ways: it goes along with what a scientist does as far as the observations, recording data.
>
> (George, interview)

> It's observations, which scientists do. . . We did observations and we collected data . . . We were supposed to collect data each night and the class recorded data together.
>
> (Cindy, interview)

> I have come closer to science. I felt like I was a scientist observing and discovering.
>
> (Mariah, Journal, final entry)

Three informants also discussed the need for accurate and consistent observations in science.

> I can imagine having to sit and watch some kind of bacteria all of the time, and keeping it really accurate. That's what scientists often do: like what we were doing with the moon, trying to keep good records of what we were watching.
>
> (Celine, interview)

> You have to write down what you see and you need to be consistent day after day with what you're writing, as far as what you see.
>
> (Laurie, interview)

Thus students applied the activities of the moon investigation to their conceptions of the NOS. That science is based on observation is not a hard idea for students to understand; it is a NOS idea that is emphasized in most science classes. However, we expected students to go beyond the basic understanding that science is empirical, to examine the roles that observation plays in science. For example, observation can precede or follow theory building. Observations can be used to confirm explanations or discount them. Observations are not objective, but are guided by the ideas scientists bring to an investigation. And although disconfirming observational evidence may lead to theory change, often it is ignored. In the moon investigation, only a few students mentioned such features of observation. In particular they noted that observation in science can occur at different places in an investigation, and that observations might be biased based on the scientist's theory.

> Scientists will come up with some ideas or predictions and then try to observe and test their data or test their ideas and try to get some data for their ideas.
>
> (Celine, interview)

> I think that might happen sometimes in science too, where the scientist just wants these results so they might not actually get the result but make them look like they did.
>
> (George, interview)

That more students did not mention the roles that observation plays in science may be a comment on our instruction and on the cognitive requirements of the task. To conceive of science as empirical, it was enough for students to play the role of scientists in the moon investigation. However, to understand the various roles of observation in science may have required more explicit instruction about those roles than we provided.

Scientific knowledge involves the invention of explanations

The moon investigation

We sequenced our instruction so that students would move from recording observations and looking for patterns, to making and testing predictions and inventing explanations. Once students had gathered enough data, instructors prompted them to analyse the data, explicitly encouraging them to look for patterns that emerged from their observations and to make predictions based on these patterns:

> With these patterns you can make predictions . . . in your journals make some patterns and predictions.
>
> (Field Notes, week 3)

Students also designed tests of their predictions. For example, a student who noticed a pattern in the class data that the moon appeared to move across the sky from east to west, predicted that if she observed at three different times in one evening, she would see the moon in three different locations.

We included problem-solving activities in the form of moon puzzlers, some of which focused on making predictions:

> Last week I saw the moon and it looked like a banana. This week it looks a lot larger. How long do you think it will take the moon to appear full? And then what do you think will happen?
>
> (Puzzler 1)

We designed the moon puzzlers to become more difficult over time, by asking students to move from patterns to predictions to explanations. For example, in Moon Puzzler 8, students looked at seven day's worth of moon data and were asked the following questions:

- What PATTERNS do you observe about the moon?
- What do you PREDICT the moon will look like on September 6?
- Where in the sky do you PREDICT the moon will be at 7:45 p.m. on September 6?
- How could you EXPLAIN the patterns you observed?

Thus in the puzzlers, and in class, instructors encouraged students to create their own theories to account for the patterns they had observed: 'In your journals take two patterns - the moon appears to be moving and the moon seems to be changing shape - and try to make an explanation that works' (Field Notes, week 4). In class, students would compare their developing explanations to others' and to the evidence that had been collected, and evaluate their explanations. We also tried to emphasize the inventive aspect of science by pointing out the differences among observations, patterns, and explanations. For example, toward the end of the moon investigation, we made a chart of things we could find out by observing (that the size of the lit portion of the moon was increasing or decreasing) and things we could not find out by observing (the relative position and motion of the Earth, moon, and sun). Instructors asked students to write about their ideas, emphasizing that their explanations went beyond observing.

> Try to put all of this [evidence] together and try to give an explanation. Some of the ideas you have in your journals can't be answered by looking, you have to make up an explanation for it.
>
> (Field Notes, week 4)

Thus we tried to help students see that science was not only empirical, but also relied on the interpretation of evidence and creation of explanations.

We also used models as a way for students to explain their ideas: 'I highly recommend you make a model [to see] if the light from the sun reflects on the moon' (Field Notes, week 4). We provided students with Styrofoam balls to model their theories:

> I am hearing that you are trying to put all these things together; I'm gonna give you a ball to play around with; you have to invent an explanation; you have to put it together by yourself . . . see if this model confirms what you are talking about or not.
>
> (Field Notes, week 5)

Our goal was for students to distinguish between the activities of observing and explaining and realize that scientific knowledge involves not only observing, but also inventing ideas to account for observations or to lead to new observations.

Student Conceptions

When asked to describe the patterns they were noticing and to predict the moon's size and shape, some students said, 'It's moving from east to west', 'It's getting bigger. . .it will progress until full moon on Sunday (Field Notes, week 3). In their journal entries, students described patterns they noticed, made predictions, and posited explanations. In the following excerpts we have labelled student journal entries with the types of statements made.

> Once again I got to check the moon. Again I was walking east and the moon was in the sky higher than it was yesterday. (PATTERN) I think this is because the moon moves across the sky. (EXPLANATION)
>
> (George, week 3)

> The moon is becoming larger because the Sun is hitting more of its surface. (EXPLANATION) I don't exactly know why but it does. So I will again say that tomorrow the moon will appear larger. (PREDICTION)
>
> (George, week 4)

> It's starting to go from the other side, it's starting to go away from the right side. (PATTERN) I suspect it's gonna be totally gone soon. (PREDICTION)
>
> (Celine, week 9)

In Mariah's journal, we can see her observing, finding patterns, predicting, explaining, and asking questions that arise from the data:

> I am observing that the moon is waxing. It seems to be getting bigger. I also can't believe how much it has moved on the sky in one day. (PATTERNS) What determines how far it moves? (QUESTION) (week 3). I can't really predict I just know it will be farther to my right hand when observing from my observation spot. (PREDICTION) (week 3). I think the definite reason for not seeing the moon is because of the weather. (EXPLANATION) I think if I could see it, it would almost be a full moon. (PREDICTION) If I could just move the haze I could see if my prediction was right. I have come to the conclusion that the moon rises in the SE and sets in the SW. (PATTERN) I have made this from analyzing the class data. I am

> going to observe the moon throughout the night to check my prediction (week 3). I looked in the Southwest to see if it was on it's [sic] way to setting, but I did not see it. This is where my question comes in. Where is the moon? I noticed that it is coming out later at night and in the morning. Why isn't it visible now? (PATTERNS AND QUESTIONS) Well, the sun comes out later, so maybe the sun doesn't shine on the moon until later at night and in the morning. But the moon that is visible in the morning seems to be part of that day's moon because it was seen rising in the same area as the sun (EXPLANATION).
>
> (Week 5)

Some of the students actually labelled their own journal entries as patterns, predictions, or explanations:

> As far as *patterns* I have noticed that there are several patterns to the moon. First, I have noticed the phases: no moon, little view of moon, moon gets bigger (waxing), moon gets smaller, no moon or new moon. The phase repeats over and over. I have also noticed that you can *predict* where the moon might be if you follow rise/set times. I know that the moon rises in the east and sets in the west.
>
> (Cindy, week 4)

> Patterns: Starting in the east, moving west; Moon is getting bigger; The moon moves east to west and is getting smaller daily. Predictions: The moon is going to start getting smaller now; The moon will be smaller tomorrow. (Michelle, week 4) Explanations: The phases of the moon are determined by the positioning of the moon in comparison to the Earth.
>
> (Michelle, week 5)

Although many could distinguish observing, predicting, and explaining in their own thinking, only one student transferred the inventive aspect to scientists' work:

> Scientists will come up with some ideas or predictions and then try to observe and test their data or test their ideas and try to get some data for their ideas and that's what we were doing.
>
> (Celine, interview)

By the end of the moon investigation, our students described science as an empirically based activity that involves making predictions, yet most of them seemed to disregard the inventive aspect of science. Although many class activities provided students with opportunities to make sense of the creative aspect of the NOS by reflecting upon the differences among observations, patterns, predictions, and explanations, students seemed not to make the connections between their own learning processes and the NOS.

Scientific knowledge is socially embedded

The moon investigation

We structured the moon investigation to illustrate the idea that science is a social enterprise. We had three goals in mind related to the social nature of science, namely, that students recognize that: 1) scientific knowledge is socially constructed through open communication; 2) disagreements in the scientific community are resolved through dialogue; and 3) observations, models, and explanations are subject to evaluation by this community. We did not emphasize the culturally embedded nature of science in the moon investigation.

We facilitated open communication in the classroom by having the students sit in small groups of four or five. In these small communities, students shared and discussed their observations about the moon, noted patterns, generated explanations, and tested their theories. Small groups presented the results of their discussions to the larger classroom for consideration. Tracey recounted these experiences:

> I think the major part for people was being consistent in collecting data . . . and then writing so that everyone could understand it or being able to explain it so that everyone could understand it.
>
> (Interview)

We hoped that such discussions would encourage students to recognize that, in the scientific community, disagreements may arise during the evaluation of data or theory, but are eventually resolved. Large group discussions were the regular forum for individuals and small groups to present their data, interpretations, and explanations for consideration. All presentations were accepted with 'organized skepticism' (Merton 1973). Often students' moon drawings differed with respect to position or size of the moon at a particular time. We would use such opportunities to probe student thinking: 'Is it that your drawings are not very good? Or is it your observations?' (Field Notes, week 3). We discussed the differences and looked for evidence to resolve the discrepancies. Sometimes this evidence came from students sharing their data; other times we asked students to pay attention to the point of contention in subsequent observations or consult outside resources such as moon calendars posted on the Internet.

One day several students claimed that they had seen a sliver of the moon with a backwards 'C' shape in the early evening. Another student claimed that she had seen a full moon at eleven in the morning. She described its location and how it looked peeking from behind the clouds. An argument ensued as to whether or not the moon could be seen both during the day and at night, and could be both full and crescent on the same day. Subsequent observations, data postings, and discussions led the second student to reconsider her position. Cindy recounted such discussions in her interview:

> I liked seeing how it moved across the sky in the pictures. It was also neat to see how sometimes they would draw the moon in various ways, like they weren't exactly the same and they brought up good discussions on it. Is that a misinterpretation? Or is someone not drawing it well enough? Or is a different amount of light reflecting off it? And that really helped.
>
> (Interview)

Halfway through the moon investigation, one of the classes reviewed a chart of the students' initial explanations for the phases of the moon. A debate arose as to whether or not the phases of the moon were caused by the shadow of the Earth falling on the moon. The instructor gave each of the students three small balls to represent the Earth, moon, and sun, and asked them to come up with a theory that would either support or refute this idea. Annette's table came up with an alternative to the Earth shadow theory that more closely resembled the scientifically accepted idea. Annette explained, demonstrating with the balls, that the positions of the Earth, moon, and sun affect how we see the phases. The class enacted her theory, using human models for clarification. The instructor then asked the students to debate this issue in their small groups based on their evidence and understanding of the moon thus far. Next, students tested Annette's theory using flashlights and Styrofoam balls. Finally, the instructor asked them to write their evaluation of this theory in their journals. Students wrote:

> Does the Earth cast a shadow on the moon? I don't think so. I think the moon casts more of a shadow on the Earth when we don't see it (new moon phase).
>
> (Michelle, week 5)

> The phases of the moon are not due to the Earth's shadow but the reflection of the sun's rays off the moon when the moon is between the sun and the Earth.
>
> (Fred, week 5)

> The moon could not be seen tonight. The reason is not because the Earth shadows the moon . . . The sun provides the glow of the moon. When the moon moved between the sun and the Earth, the sun lights only that half, and the dark part is facing the Earth.
>
> (Tracey, week 6)

These journal entries exemplify students using and evaluating community theories as a way to enhance their own explanations of the phases of the moon. As instructors, we hoped that classroom discussions would acquaint students with the role of the scientific community in the evaluation and understanding of scientific ideas.

Student Conceptions

By the end of the course, eight of the 11 participants mentioned that classroom discussions were an integral component in their construction of understanding about the moon phases. Sharon wrote in her journal:

> The class discussions helped me to learn more about what was happening to the moon. The information that was presented every day allowed many of my questions to be answered and data to be confirmed.
>
> (Journal, final entry)

For most students, constructing scientific knowledge in a social setting was a way of learning contrary to their previous experiences in science classrooms:

> That's how all my science classes have been up to this point, they've all been: this is this and this is this, it's been more right and wrong answers, rather than trying to figure out if it's right or wrong . . . Now we are trying to figure out the phases, it was more like it came up in discussion.
>
> (Cher, interview)

We used small group and large group discussions to model the role of constructing, testing, and evaluating scientific knowledge in a scientific community. Students credited discussion as a means to 'clarify differences in records' (Andy, interview), 'get explanations' and 'discuss conflicts' (Fred, interview), 'see discrepancies' (Cher, interview), and 'correct mistakes' (Laurie, interview). George summed it up as follows:

> In this way [small group discussions] people . . . could draw what they were saying on paper and maybe try to make you understand . . . And you always had disagreements, like when you do something people would ask 'Why? Are you sure?' So there was always people asking or making sure you were right or pushing you to explain it better.
>
> (Interview)

Although most students could appreciate the value of these discussions in constructing their knowledge about the phases of the moon, only five of the 11 participants were able to apply this social dimension to the work of scientists. Of these five, four referred to the social aspect as a process of science. For instance, students said that scientists 'work well in groups' (Michelle, interview), 'communicate with others' (Tracey, interview), 'collaborate with others' (Laurie, interview), and 'help to do research, not just one person does it' (Sharon, interview).

Tracey appreciated that scientists communicate like we had in class. However, she failed to see that scientists bring their own values and experiences to the forum. She was often frustrated with her small group discussions because she left the discussion trying to 'figure out' why she understood the concept the way she did. She contrasted this with 'real' science. 'We came from a lot of different backgrounds and former experiences', whereas 'real' science would be 'exact ... in detail, the methods and the processes' (Interview). Tracey thought her struggle to understand and get her group members to see her point of view was not part of how the scientific community works. Likewise, none of the other informants mentioned the influence of experience or background on the development of scientific knowledge.

Only one student discussed the role of collaboration in the generation and validation of scientific ideas:

> That's what scientists have to do too. We had our individual ideas and we had to weigh and make sure that other people could do the same thing that we did, or find the same ideas that we did on our own, when we talked about it together.
> (Celine, interview)

Although students acknowledged the value of learning scientific concepts via collaboration, the transfer of this knowledge into the realm of the NOS was limited. Apparently our explicit valuing of a learning community did not lead to student understanding of the social dimensions of science itself.

Conclusion

Our findings show that student appreciation of the empirical, inventive, and social features of the NOS was limited primarily to processing their own learning, rather than applying their conceptions to the activities of scientists. While students realized that scientists make observations and use them as the basis for generating patterns and predictions, they failed to recognize some of the more complex roles of observation in science. Students could separate the processes of observing, noting patterns, making predictions, and generating explanations in their own learning, but did not articulate the role of invention in science. Similarly, students valued the social dimensions of learning, but were unable to apply them to the activity of scientists.

These findings are significant for us as we rethink our moon investigation pedagogy. We realize that, although our intentions were to be explicit about the NOS, our attempts to illustrate the NOS during the moon investigation were often more implicit than explicit. We were explicit about students' learning processes, but often failed to make the link to the NOS. Although we modelled the activities of scientists, seldom were students asked to think about how the science they were doing in class was related to what scientists do. To improve our students' understanding of the NOS, we realize that this question should be a recurring part of the moon investigation.

We plan to make these features of the NOS more explicit in our future instruction. We will prompt students to identify what they know about the moon and how they came to know it, distinguishing what one can come to know from: a) observation alone; b) invention; or c) sources such as teachers and texts. We will also help students focus on how incoming ideas about the moon influence observations by asking, 'Why did you choose to observe the moon at night?' or 'Why were you surprised to see the moon in the morning?' We will focus on the role of discrepant data by asking questions such as: 'Are all data equally important?' 'What do we do with data that do not fit our predictions or theories?' We will periodically ask each group to 'publish' their theories, and then debate their merits and failings. Thus we will emphasize the role of the scientific community in constructing and evaluating knowledge. We will also ask students to reflect more about their evolving NOS conceptions. At the start of the moon investigation, students draw a scientist and explain their ideas about what science is. We plan to revisit their responses to these tasks periodically so they can examine if their ideas about the NOS are changing. At the end of the study, students write a final reflection on their learning. We will require that they also discuss how they think the moon investigation relates to the NOS. It is our hope that these modifications will help the moon investigation achieve our intended goal, to enhance student understanding of the NOS.

This study corroborates previous research (Abd-El-Khalick *et al*. 1988) concerning the need for explicit instruction in the NOS. It also demonstrates the importance of self-study in improving teaching. We intended to be explicit about the NOS in our teaching of the moon. Through self-study we recognized that, although we were explicit about our students' science learning, we did not help them make direct connections between the activities of the moon investigation and the activities of science. We could never have understood this by examining our students' responses alone; we also needed to examine our practice.

Understanding the context of the moon investigation is important in thinking about the implications of this study. We are teacher educators, not astronomers or philosophers. We teach science within the context of a science teaching methods course, where student understanding of science and the NOS is but a small portion of our learning goals (Abell and Bryan 1997). Through action research, we continually rethink our teaching in light of the evidence for student learning. The same reflective processes that we expect of the prospective teachers in our course, we require of ourselves. New goals for student learning (e.g., National Research Council 1996), have implications for teacher learning. Yet, according to Bransford *et al*. (1999), 'Teacher learning is relatively new as a research topic, so there is not a great deal of data on it'. Our study adds to the literature on teacher learning by examining the learning of both the future teachers in the course and the teacher educators who instructed them. In this paper we have demonstrated the importance of reflecting upon our teaching, and thinking about how our strategies helped or hindered student understanding of the NOS. Our study has brought us full circle back to taking action on our future teaching. We believe that our work can help others who are engaged in science teacher education take action on their teaching as well.

Notes

1. A previous version of this paper was presented at the 5th International History, Philosophy and Science Teaching Conference in September 1999 in Como, Italy.

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