Fostering Scientific Thinking by Prospective Teachers in a Course That Integrates Physics and Literacy Learning

By Emily H. van Zee, Henri Jansen, Kenneth Winograd, Michele Crowl, and Adam Devitt

We designed a physics course for prospective elementary and middle school teachers to foster aspects of scientific thinking recommended in reform documents. Because the elementary school curriculum focuses heavily on literacy, we also explicitly integrated physics and literacy learning in this course. By integrating physics and literacy learning, we mean learning to speak clearly, listen closely, write coherently, read with comprehension, and make and critique media resources competently in physics contexts. Thus a major focus of our efforts has been designing activities and assignments that build literacy skills while engaging prospective teachers in scientific thinking. The National Research Council (2007) suggested that students who are proficient in science (a) know, use, and interpret scientific explanations of the natural world; (b) generate and evaluate scientific evidence and explanations; (c) understand the nature and development of scientific knowledge; and (d) participate productively in scientific practices and discourse. In this paper, we discuss prospective teachers' perceptions of ways they have developed their abilities to think scientifically in this course.

This is a progress report on efforts to establish a physics course for prospective elementary and middle school teachers at a research university. With support from the National Science Foundation (NSF), we have developed a physics course that emphasizes questioning, predicting, exploring, and discussing what one thinks and why. Our goal is to engage prospective teachers in learning science in ways that reform documents recommend that they teach science (National Research Council [NRC], 1996, 2007, 2012).

We also teach the course in ways that integrate physics and literacy learning. By integrating physics and literacy learning, we mean learning to speak clearly, listen closely, write coherently, read with comprehension, and make and critique media resources competently in physics contexts. This project contributes to more than 2 decades of research on the role of literacy in science education (Yore & Treagust, 2006).

Inquiring into physical phenomena

Design of the course has been a collaborative effort by the instructor (van Zee), a former middle school science teacher and now science education faculty member; the chair of the Physics Department (Jansen); a literacy professor (Winograd); a graduate assistant, who is a former museum educator (Crowl); and another graduate assistant, who is a former elementary school teacher (Devitt).

The physics course meets for 2.5 hours twice a week for 10 weeks. Participants are primarily female early childhood development and education majors. Because the course is experimental, we restrict entry to 16 students. The prospective teachers work at tables in small groups of three or four.

We have drawn on several curricula developed with NSF support: *Powerful Ideas in Physical Science* (American Association of Physics Teacher, 2001), *Physics and Everyday Thinking* (Goldberg, Robinson, & Otero, 2008) and *Physics by Inquiry* (McDermott & the Physics Education Group, 1996). All engage students in exploring physical phenomena, developing scientific explanations based on evidence, and articulating their understandings in clear and precise ways. We are developing activities and materials to supplement such curricula for instructors interested in modeling strategies that integrate science and literacy learning (van Zee, Jansen, Winograd, Crowl, & Devitt, in press). The course wiki (http://physics.oregonstate.edu/coursewikis/ph111) provides examples of these strategies.

The guiding question for the course is: What happens when light from the Sun shines on the Earth? Units include the nature of light phenomena, the nature of thermal phenomena, the influence of light and thermal phenomena on local weather, the influence of light and thermal phenomena on global climate, the nature of astronomical phenomena such as the phases of the Moon, force and motion, and reflection on science teaching and learning.

Assignments foster speaking, listening, writing, reading, and critiquing media about relevant topics. The prospective teachers, for example, interview children and adults to document common ideas about the phenomena they are exploring, engage friends and family members in similar explorations (Crowl, 2010), read articles by teachers reporting on children's explorations (e.g., Roberts, Bove, & van Zee, 2007), write a paper documenting their own learning, and make and critique relevant websites. Class sessions include explicit discussions of literacy strategies (Devitt, 2010).

Engaging prospective teachers in scientific thinking

A major focus of our efforts has been designing activities and assignments that build literacy skills while engaging the prospective teachers in scientific thinking. In *Taking Science to School: Learning and Teaching Science in Grades K–8,* the NRC (2007) suggested that students who are proficient in science (a) know, use, and interpret scientific explanations of the natural world; (b) generate and evaluate scientific evidence and explanations; (c) understand the nature and development of scientific knowledge; and (d) participate productively in scientific practices and discourse.

We have been curious whether the prospective teachers perceive that they have been developing these aspects of scientific thinking. Near the end of each course, we have asked the prospective teachers ($n = 9$, spring 2009; n = 14, spring 2010; n = 15, spring 2011) to discuss the four proficiencies from the NRC report. Then in a homework assignment, we have asked them to reflect on ways in which the course helped them develop these proficiencies. Figure 1 shows a prompt for this assignment. We discuss next some of their responses, along with some additional examples drawn from other assignments.

Knowing, using, and interpreting scientific explanations of the natural world

During a class discussion near the end of the course, the prospective teachers usually agree that they have been developing the first proficiency during their extended exploration of the phases of the Moon. This exploration starts during the first week of class when the prospective teachers respond to a series of diagnostic questions about why it gets dark at night, why it is cold in the winter and hot in the summer, why the Moon seems to have different shapes at different times, how they would define a scientific explanation, and how they would describe inquiry approaches to learning and teaching. After watching the Moon through two cycles and developing an explanatory model for the Moon's changing phases, they respond to the same questions again during the eighth week of the course. In writing a paper reporting on their exploration of the phases of the Moon, they use their initial and current responses to these diagnostic questions as evidence for changes in their understandings. They write sections of this paper for homework over several weeks, with feedback provided for each draft. The last section of the paper is a reflection on their learning, framed by the four proficiencies articulated by the NRC report (2007). The complete paper is due at the next class session after the discussion. Table 1 presents one prospective teacher's response. She not only described new understandings about the phases of the Moon, but also her new interest in sharing that knowledge with others.

Generating and evaluating scientific evidence and explanations

In discussing the second proficiency, a prospective teacher stated, "The pinhole camera provided us with empirical evidence to construct and defend our argument that light leaves a source in all directions and in straight lines." The pinhole camera exploration engages small groups in vigorous conversations with one an-

FIGURE 1

Prompt for assignment to reflect on ways the course helped the prospective teachers develop the four proficiencies articulated in *Taking Science to School* (NRC, 2007, p. 36; http://books.nap.edu/openbook.php?record_id=11625&page=36).

A recent document published by the National Research Council has articulated four proficiencies that teachers should develop in their students.

Students who are proficient in science:

1. know, use, and interpret scientific explanations of the natural world;
2. generate and evaluate scientific evidence and explanations;
3. understand the nature and development of scientific knowledge; and
4. participate productively in scientific practices and discourse.

Please include in your reflection for the Moon paper and post on BlackBoard ways in which you think that exploring light phenomena and watching the Moon have helped you develop these proficiencies this term—or not helped you do so if that is the case. It's OK to be critical as that is how this course will improve.

other while generating explanations of an intriguing phenomenon—that a lightbulb appears upside down when viewed through pinhole cameras. They make these devices with toilet paper tubes, wax paper, and aluminum foil with a pinhole (http://www.exploratorium.edu/IFI/activities/pinholeinquiry/viewer.html). In developing explanations of pinhole phenomena, small groups use large whiteboards to present powerful ideas about light that emerge in their discussions. With gentle guidance from staff members, they support these ideas with evidence drawn from their explorations.

Table 2 shows an example of an explanation generated by a small group. This was part of a website that this small group created near the end of the light unit in Week 4. They used free software developed by the Carnegie Foundation for the Advancement of Teaching, now available at http://www.merlot.org. The group's website (http://contentbuilder.merlot.org/toolkit/html/snapshot.php?id=48464235615418) includes a photo of their whiteboard with a ray diagram and explanation for the pinhole phenomenon. Preparing such whiteboards for presentation and building such websites collaboratively in class provide many opportunities to speak clearly about one's own ideas, listen closely to another's understandings, and write coherently in physical science contexts.

Understanding the nature and development of scientific knowledge

A prospective teacher opened discussion of the third proficiency by stating, "The third strand focuses on students understanding that science and science concepts are modifiable. Scientists and/or students don't always observe everything that is happening at first. As their exploration continues, their concepts and models can be reconstructed to fit their new findings." She continued by providing the example shown in Table 3 in which she reviewed Galileo's discussion about falling objects and reflected on our exploration of this topic.

In class, the prospective teachers respond to the diagnostic question, "Two balls are dropped from the same height at the same instant. The balls have the same diameter but different weights. Which hits the ground first, the heavy ball or the light ball? Or do they both land at the same time? Why?" Most predict the heavy ball would land first. Next, three prospective teachers role-play an excerpt from Galileo's (1638/1914) *Dialogue Concerning Two New Sciences*. In this dialogue, Salviati, Segredo, and Simplicio discuss Aristotle's claim that heavy objects fall faster than light objects. When the prospective teachers test this claim, they find to their surprise that heavy and light objects, released at the same time from the same height, hit the floor at the same time. They also compare the force needed to push a lead brick and a Styrofoam brick, to realize that although the Earth pulls on a heavy object with

TABLE 1

Example of Strand 1: Knowing, using, and interpreting scientific explanations.

Changes in	Prospective teacher's comment
Knowledge and attitude	Throughout the last two months, my knowledge about the Moon, as well as my attitude towards learning about the Moon, has changed drastically.
Understandings about the causes of the phases of the Moon	I have learned why the Moon goes through its phases and that it is not the Earth casting a shadow on the Moon.
Understandings about when the Moon is visible	I have changed my thoughts on when the Moon is visible to us. I know now that the Moon is visible just as often during the day as it is at night.
Knowledge of eclipses	I now understand and have confirmed what causes lunar and solar eclipses.
Ability to visualize relevant geometrical relationships	I know that the angle between the Moon and the Sun (as seen by pointing one arm at the Moon and one arm at the Sun) directly affects how we see the Moon.
Attitude toward science	More important, I have learned that science can be fun and interesting.
Attitude toward learning	(I learned) that many times learning is more effective when you are forced to learn for yourself and you are not just given answers.
Behavior	The past week the sky has been very clear and I have found myself searching for the Moon every day. I am excited when I see it and I point it out to the people I am with.
Appreciation of natural phenomena	It is amazing how different seeing the Moon is now that I know why and how I am seeing what I am seeing.
Explicit goal as a teacher of science	I hope someday to be able to instill this same awe and wonder on many of my students using the same approaches I have learned in this class.

a bigger force than on a light object, the heavier object's greater inertia makes it harder to get moving. Table 3 shows this prospective teacher's summary of Galileo's logical arguments and reflection on her group's experiments with falling objects. She wrote, "We found that our first notions are not always complete or accurate. Our scientific theories can always be modified with newly found evidence." Closing with a YouTube video of astronauts dropping a hammer and feather on the Moon, this historical context opens explicit discussion of many aspects of the nature of science, including the roles of logical argument, experimental evidence, and societal beliefs and practices.

Participating productively in scientific practices and discourse

In discussing the fourth proficiency, the prospective teachers seem to value their thoughtful interactions as well as the explorations. For example, one wrote, "We developed our understanding of the Moon over time, refining our ideas, creating new experiments to gather more data and evidence. And best of all, we learned that each and every one of us could understand science, and be scientists. We weren't afraid to share what we didn't understand, to ask questions of each other, to help each other."

As they gain confidence, the prospective teachers conduct interviews with children and adults to hear typical ideas about a topic and to think about explanations they might hear while teaching. After making observations and developing an explanatory model for the moon's changing phases, for example, one of the prospective teachers interviewed her roommate and reported that the roommate "argued with me a lot and was very insistent that she was not wrong. She was confused, so I got out my flashlight and my 'moon' ball and had her do the same experiment we did with it, trying to see when the 'moon' was 'full,' 'new,' and 'half.'" This prospective teacher's new understandings were robust enough to engage the roommate in an exploration to convince her that the Earth's shadow does not cause the phases of the moon.

After learning about argumentation strategies in class with a related reading assignment, a prospective teacher commented on arguing as a collaborative process: "An important part of thinking scientifically is being able to support what you say with data. It is also important to build on your ideas by collaborating with others." Homework assignments also include making connections outside of class by exploring physical phenomena with friends and family members in ways similar to our investigations in class or inviting them to join in critiquing related websites (Crowl, 2010; Crowl, Devitt, Jansen, van Zee, & Winograd, 2013). A student engaged a roommate, for example, in exploring how a dot on the inside of a cup appears to move when water is poured into the cup until it passes the dot. Table 4 presents her reflection on facilitating scientific discourse with her roommate while exploring this interesting phenomenon.

Acknowledging frustrations

Given the invitation in the prompt to include negative comments, several prospective teachers noted some frustrations. These concerned our instructional approach, expectations, and curriculum.

Initially our instructional approach puzzles many of the prospective teachers. One wrote, for example, "When I first came into this class I

TABLE 2

Example of Strand 2: Generating and evaluating scientific evidence and explanations.

Explanation	Small group's explanation of pinhole phenomena on website
Begins by stating powerful ideas about light developed in previous session	To understand the pinhole phenomena, it is important to understand a little bit about light. Light travels in straight lines in all directions from a source. In order for humans to see, light has to travel to our eye.
Makes connection to particular situation	The pinhole camera works from these principles.
Begins to apply the principles to this situation	Some of the light from an object travels in straight lines through the pinhole in one end of the camera (aluminum foil covering one end of a paper towel roll).
States surprising observation	The image appears on the wax paper (covering other end of paper towel roll), but it's not oriented the same way as we might think. The image appears upside-down . . .
Explains surprising observation	because the rays traveling from the top of the object pass through the hole and are projected on the bottom portion of the wax paper.
Continues the explanation . . .	The light rays traveling from the bottom of the object do just the opposite and are projected onto the top of the wax paper (shown in diagram).
and applies the second principle	Then, the light from the image travels to our eyes.

had a hard time with not getting direct answers to my and other students' questions." However, she continued with a positive remark, "After being in here for a term I have really come to appreciate having to slowly learn concepts by observing and talking with one another. I really enjoy all of our own investigations and experiments to have things make sense to us."

We try to mitigate this initial negative reaction through explicit discussion of our teaching practices. We begin the course on Day 1, for example, by having the prospective teachers create a poster in small groups to illustrate what they already know about light and to generate a list of aspects that had fostered that learning. After introducing themselves to the whole group by presenting their posters, the prospective teachers create a class list of factors that had fostered their learning. Typically the list includes some version of student agency such as "student generated experiment" or "questioning" (van Zee & Roberts, 2001). We post this student-generated list on the wall of our laboratory, state that we hope to model these successful strategies in this course, and often refer to the list in explicitly talking about why we choose to teach in the way we do.

We set high expectations for mastering mathematical representations. Another prospective teacher stated, for example, "When working with motion detectors and velocity and acceleration graphs, my classmates and I became very frustrated. At times, we did not feel like trying to read velocity and acceleration graphs anymore." We want the prospective teachers not only to be able to "tell the story" represented by motion graphs, but also to be able to translate flexibly among them, an expectation most find challenging. This prospective teacher also continued with a more positive statement: "My instructors . . . taught us to break down the graphs into small sections and to interpret them carefully. The most important thing they instilled in us, though, was to keep trying . . . . Each and every one of us in the class can now explain what is happening at each phase of a velocity or acceleration graph."

Our exploration of light phenomena culminates in the Moon studies, which require ongoing observations, sometimes difficult in our frequently cloudy skies. A prospective teacher commented, "At times I would have to say I did get frustrated because we were unable to see the Moon." She too followed this with a positive remark, "But in the last few weeks I have really enjoyed being able to see the Moon now that I have more knowledge and a greater appreciation for what can be seen."

One of the prospective teachers offered a practical suggestion: "Looking back I wish I would have known about these four standards going into the class because they would have given

TABLE 3

Example of Strand 3: Understanding the nature and development of scientific knowledge.

Commentary	Prospective teacher's comment
Makes general statement that science knowledge is tentative	Science concepts are modifiable. Scientists and/or students don't always observe everything that is happening at first. As their exploration continues, their concepts and models can be reconstructed to fit their new findings.
States connection to course	I found this strand most applicable when we were studying Galileo.
States Aristotle's view	In class I wrote that Aristotle first thought that objects of different masses fell at different rates. A light object would fall at a slower rate than the heavier object.
States first part of Galileo's logical argument	Galileo argued that if the two objects (light and heavy) were tied together, the light object would slow the heavy object down, and the heavy object would speed the light object up (together they would fall somewhere in between).
States second part of Galileo's logical argument	Galileo further challenged this thought process by stating that if two objects are tied together, their mass combined would be even heavier than the original heavy object. This would mean the tied together objects would fall faster.
States Galileo's conclusion based on contradiction	The two objects together cannot both fall slower and faster than the original heavy object, so all objects must fall at the same rate!
Reflects on sense-making dialogue	In the story we read in class, Simplicio was trying to hear both points of Aristotle (Salviati) and of Galileo (Segredo) and make sense of them.
States Galileo's conclusion based on logic	When their theories/thought processes were contradictory, Simplicio (Galileo's final thought process) believed that because of this, objects of different masses must fall at the same rate.
States next step of testing conclusion	This still was not proven as "fact" or "discovery" until it was supposedly tested by dropping objects from the Tower of Pisa.
States connection to own exploration	We found that our first notions are not always complete or accurate. Our scientific theories can always be modified with newly found evidence.

me an idea about the expectations for this class. I feel like I was a little clueless and it caused me to not benefit as much as I would have liked from the course (especially earlier in the term).” She went on to recommend that we begin the course by discussing these proficiencies right away. From our perspective, the student-generated list of aspects that had fostered their science learning provides similar guidance. However, we acknowledge the usefulness of adding the NRC’s voice of authority to the message.

Implications

This has been a progress report that describes ways in which students in our physics course for prospective elementary and middle school teachers developed abilities to think scientifically in the context of integrating physics and literacy learning. We have presented evidence of such thinking primarily from student responses to activities and assignments that explicitly requested reflection upon their own and others’ learning processes.

Our course is aligned with calls for reform that teachers should learn science in the ways they are expected to teach science (McDermott, 1990, 2006). Special physics courses for teachers can be difficult to undertake for both instructors and students, however, if they are not accustomed to developing explanations based on observations and vigorous conversations in class. Volkmann and Zgagacz (2004), for example, described the puzzlement and ongoing development of a graduate student assistant whose own learning experiences had only involved listening to lectures and memorizing the information presented.

Some instructors—limited to the lecture format but interested in providing opportunities for students to talk with one another about what they think and why they think that—have incorporated short episodes of peer instruction (Mazur, 1997) into lecture formats. They pose a question with multiple answers, ask students to indicate their choice with clickers, and then invite students to talk with neighbors about their reasoning. A repeat round of responses with clickers typically yields improved performance, both on the immediate question in class and later on subsequent exams (Hake, 1998).

We suggest that versions of our assignments may be appropriate similarly for fostering scientific thinking in the standard science courses that are taught in a large lecture format. One issue with assigning homework in large lecture courses is managing the grading. We suggest an occasional assignment in which students post their reflections on an electronic discussion board after interviewing others about relevant topics or engaging friends and family in exploring a topic with simple equipment available in homes. Such reflections can be graded rapidly on the basis of completion rather than carefully for scientific accuracy as they simply report what people said or what happened. Asking students to write reflections on relevant prior experiences also provides opportunities to engage in thinking about a topic without the necessity of the instructor monitoring closely the content. In addition, quickly reading over responses to such assignments can give instructors insight into ideas that need addressing as well as resources on which to build. Such reflections can alert instructors to ways to make connections for the students between the science topics

TABLE 4

Example of Strand 4: Participating productively in scientific practices and discourse.

Reflection	Prospective teacher’s reflection on dot experiment with roommate
Notes roommate’s interest	I showed my roommate the experiment and she thought it was really interesting.
Reports roommate’s questions	She asked some questions like: Did it really move? and Why can I see it there now when I couldn’t before?
Names relevant physical phenomena	This gave me the opportunity to share the idea of refraction.
Explains phenomenon	I explained that light travels in straight lines and it travels in all directions, which she understood, but I told her that when it hits the water it refracts, changing the angle slightly.
Reports roommate’s continued interest	She thought this was really cool and wanted to try it again so she could watch the dot move up, even though she knew that it did not actually move . . .
Explains the phenomenon in more detail	but rather the light ray that was coming off the dot had been refracted by the water giving the illusion that the dot had moved positions.
Makes connection to teaching practices	I learned how to introduce a new topic to someone . . .
Makes connection to scientific practices and discourse	and make sure they got the chance to ask lots of questions and do the experiment again.

they are presenting and the students' everyday lives.

Although these assignments were developed in the context of a physics course for prospective teachers, similar assignments also would be appropriate in education courses on methods of teaching science. In such courses, instructors could focus attention on the various ideas documented through the interviews and informal explorations. Such assignments provide opportunities for prospective teachers to practice eliciting student ideas, to learn to listen for and notice what an individual is saying and thinking, and to begin building a repertoire of ways to engage individuals in refining the knowledge with which they begin learning a topic. This seems to us to be the essence of preparing teachers to teach. ■

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Emily H. van Zee (Emily.vanZee@science.oregonstate.edu) *is an associate professor in the Department of Science and Mathematics Education, College of Science;* ***Henri Jansen*** *is chair of the Department of Physics, College of Science;* ***Kenneth Winograd*** *is an associate professor in the Department of Teacher and Counselor Education, College of Education;* ***Michele Crowl*** *is a graduate student in the Department of Science and Mathematics Education, College of Science; and* ***Adam Devitt*** *is a graduate student in the Department of Science and Mathematics Education, College of Science, all at Oregon State University in Corvallis, Oregon.*