J Sci Teacher Educ
DOI 10.1007/s10972-012-9323-y

Integrating Physics and Literacy Learning in a Physics Course for Prospective Elementary and Middle School Teachers

Emily H. van Zee · Henri Jansen · Kenneth Winograd · Michele Crowl · Adam Devitt

Abstract The ability to listen closely, speak clearly, write coherently, read with comprehension, and to create and critique media offerings in science contexts is essential for effective science teaching. How might instructors develop such abilities in a physics course for prospective elementary and middle school teachers? We describe here such a course, involving collaboration among physics, science education, and literacy faculty members and two graduate assistants. Meeting twice a week for 10 weeks, the course emphasized questioning, predicting, exploring, observing, discussing, writing, and reading in physical science contexts. We report common themes about aspects that fostered or hindered science and literacy learning, changes in views about science teaching and learning, and positive shifts in interest in science and intended teaching practices.

The opinions expressed are those of the authors and do not necessarily represent those of the granting agency.

E. H. van Zee (✉) · M. Crowl · A. Devitt
Department of Science and Mathematics Education, Oregon State University, 301 Weniger Hall, Corvallis, OR 97331, USA
e-mail: Emily.vanZee@science.oregonstate.edu

M. Crowl
e-mail: michelecrowl@gmail.com

A. Devitt
e-mail: adamdevitt22@gmail.com

H. Jansen
Department of Physics, College of Science, Oregon State University, 301 Weniger Hall, Corvallis, OR 97331, USA
e-mail: physchair@science.oregonstate.edu

K. Winograd
Department of Teacher and Counselor Education, College of Education, Oregon State University, 104 Furman Hall, Corvallis, OR 97331, USA
e-mail: winograk@oregonstate.edu

Published online: 08 November 2012

Keywords Physics · Prospective teachers · Literacy learning

Introduction

The scholarship of teaching and learning (Shulman 2004) refers to inquiries by faculty into their own teaching practices and students' learning. This study reports upon such an inquiry into ways to integrate physics and literacy learning in a physics course for prospective teachers.

The term *literacy* is associated with many meanings. *Scientific literacy*, for example, typically refers to understanding the nature of science. We use the term *literacy*, however, as it is used in schools. A leading literacy textbook defines *literacy* in terms of the acts of listening, speaking, reading, writing, and critiquing multi-media sources such as television, movies, and the Internet (Cooper and Kiger 2006).

Our intent is to foster prospective teachers' ability to:

- listen closely to another person's thinking, even when those thoughts are expressed in fragments, with many starts and stops, as the speaker searches for words to express an idea about physical phenomena that may be forming as the speaker speaks
- speak clearly, to be able to articulate well what one is thinking and why in physical science contexts, and to summarize the thinking expressed by others as well
- write coherent scientific explanations that utilize relevant physics principles in analyzing and explicating physical phenomena
- read with comprehension literature about physical phenomena
- create multimedia representations of one's own science learning
- judge the credibility of scientific information obtained from various media.

The ability to listen closely, speak clearly, write coherently, read with comprehension, and to create and critique media offerings in science contexts is essential for effective science teaching. Recent calls for reform in science education have included attention to such literacy issues. The strands of science proficiency articulated in *Taking Science to School* (National Research Council 2007), for example, include "Participate in scientific practices and discourse" (p. 2). This study contributes to the literature an example of ways in which science faculty can nurture such abilities while developing understandings of natural phenomena.

Literature Review

Below we discuss why integrating science and literacy learning is desirable in schools and why physics departments should take responsibility for preparing teachers to do this.

Integrating Science and Literacy Learning

Both literacy educators and science educators have articulated a national need to increase knowledge about the ways to prepare teachers to integrate science and literacy learning (Century et al. 2002; Saul 2004; Yore et al. 2004; Yore and Treagust 2006). Integrating science and literacy learning can motivate children to learn to read as well as deepen their understanding of scientific knowledge (Douglas et al. 2006; Guthrie et al. 2004). This is particularly important in improving the performance of second language learners and of students from high poverty homes (Greenleaf et al. 2001; Lee et al. 2005). Science and literacy learning both use inquiry and comprehension strategies such as activating prior knowledge, establishing goals, making predictions, drawing inferences, and recognizing relationships (Cervetti et al. 2006).

Encouraging teachers to integrate science and literacy learning also is a pragmatic necessity in districts that emphasize literacy instruction to the near exclusion of science. Even literacy professionals call for literacy instruction to be less of a 'bully' and more of a 'buddy' where reading and writing serve as tools in learning meaningful content rather than as isolated goals (Cervetti et al. 2006; Pearson et al. 2007). There are many ways to embed explicit literacy instruction within science contexts (Anthony et al. 2010; Douglas et al. 2006). Prospective teachers need to experience such integrated science and literacy learning if they are to teach in this way.

Need for Special Physics Courses for Teachers

The American Association of Physics Teachers and American Physical Society are collaborating in encouraging physics departments to develop model teacher preparation programs through a project known as Physics Teacher Education Coalition (www.phystec.org). Such special physics courses for teachers can address many issues (McDermott 1990, 2006). Prospective teachers need to develop the conceptual understanding necessary for the instructional approaches advocated in reform documents (National Research Council 1996, 2007, 2012). They also need to learn about resources students bring to the study of science as well as about difficulties students may encounter. In addition, teachers need to gain experience with equipment typically found in schools. Developing a positive attitude toward science is important, as teachers who dislike science may transmit this attitude to their students.

The National Science Foundation has supported development of a variety of curricular materials to address these needs at the college level. These curricula include *Powerful Ideas in Physical Science* (American Association of Physics Teachers 2001; Ukens et al. 2004), *Physics and Everyday Thinking* (Goldberg et al. 2008), *Physics by Inquiry* (McDermott, L. C. and the Physics Education Group 1996), *Workshop Physics* (Laws 2004), and instructional practices known as modeling (Hestenes 1987). Our project materials and strategies are intended to be useful as supplements in these and similar contexts.

Research Questions

A key aspect of reforming precollege science instruction involves inspiring teachers to facilitate conversations about science with their students. Such conversations are crucial for students to construct a deep understanding of a topic (Driver et al. 2000; Gallas 1995; Kelly 2007; Lemke 1990; Osborne 2010). Such conversations depend, however, upon the teacher's ability to listen closely to what the students say. Teachers who encourage student discourse are likely to hear science content that is ambiguous and incoherent. Teachers need to listen closely to such student utterances and to respond appropriately, typically by requesting clarification and justification. Teachers also need to be able to state their thoughts clearly at the point they summarize the main ideas that have emerged from a conversation. If they choose to create written summaries of what students are saying, they need to be able to write coherently, particularly if they are modeling how to develop a written argument based on evidence. In addition, teachers need to be able to seek information from a variety of sources and to help their students to comprehend what they are reading from such sources. Also important is recognizing the need to seek and read media critically, with awareness of accuracy and potential biases.

We have explored the following multi-faceted questions about our own teaching practices: How can we integrate science and literacy learning in a physics course for prospective teachers? In particular, how can we develop prospective teachers' abilities to:

- listen closely to another person trying to express ideas about physical phenomena?
- speak clearly about one's own ideas about physical phenomena, as well as to clarify, elaborate, summarize, and/or refute ideas that others have expressed?
- write coherently about physical phenomena one has explored and explained?
- read with comprehension literature about physical phenomena?
- create multimedia representations of science learning?
- critique media presenting information about physical science concepts?

Methodology

This study is an example of the scholarship of teaching and learning (Shulman 2004). Sometimes called practitioner research (Zeichner and Noffke 2001), teacher research (Cochran-Smith and Lytle 1993; Roth 2007), or self study (Loughran 2007), such studies involve examining one's own teaching practices and students' learning. We report here on development of a physics course for prospective teachers by faculty at a large research university.

We limit enrollment to a maximum of sixteen and restrict entry to students stating plans to become teachers. Typically, these are female undergraduate majors in human development and family sciences, liberal studies, or general science. They usually are freshmen or sophomores who plan to apply as juniors to the College of Education's double degree program, with a second major that leads to a license to teach. In the seven versions of the course discussed here, taught from Winter 2008 to Spring 2011, enrollment ranged from 7 to 15, with a total of 82 students.

We routinely video class sessions, archive electronic bulletin board entries, and copy homework, examinations, and reflective journals. We drew from these data to provide illustrations of activities and assignments. We also drew on data from periodic surveys. Mid-way in the Spring 2011 course, for example, we asked the following questions ($n = 15$):

1. What aspects have fostered your learning the most? Explain.
2. What aspects have fostered your learning the least? Explain.
3. How is this class different from other science classes you've taken?
4. Have the first 5 weeks of the course had any influence on how you think about teaching and learning? Why or why not? If so, how?

At the end of the course, we also asked about aspects that may have changed such as:

1. To what extent were you interested in science before this course?

Not interested	1	2	3	4	5	interested

2. To what extent are you interested in science now?

Not interested	1	2	3	4	5	interested

In addition, we asked for ratings of various components of the course such as: How interesting and useful were various aspects of this course to you? Learning about literacy strategies

Not interesting	1	2	3	4	5	interesting

Not useful	1	2	3	4	5	useful

We drew from these data to illustrate the physics activities and assignments we designed to foster integrated physics and literacy learning. Our purpose has been to document how we are teaching the course and to share examples of what students are learning. We also report here common themes in written responses to surveys as well as the mean, median, mode, and range of ratings. For the quantitative data, we used a paired t test to judge statistical significance ($p < .05$).

Design of the Course

With support from the National Science Foundation, we have been developing ways to prepare teachers to enhance literacy learning as they teach science (Jansen et al. 2006). The project involves collaboration by faculty in the College of Science and the College of Education. The course has been approved for the "Baccalaureate core." Students can choose it among others to complete the graduation requirement of three science courses.

Inquiring into Physical Phenomena meets twice a week for one ten-week quarter (http://physics.oregonstate.edu/coursewikis/ph111). Each session is two and one half hours. Emphasis is on questioning, predicting, exploring, observing, discussing, writing, and reading in physical science contexts. Course objectives include increasing abilities (a) to use understandings of physics principles to explore and explain physical phenomena, (b) to articulate ways knowledge is developed within scientific communities with examples drawn from the prospective teachers' own inquiries as well as historical cases, and (c) to integrate science and literacy learning. This study focused upon the last objective.

Preliminary Findings

A variety of activities and assignments have evolved as our answer to the question "How can faculty integrate science and literacy learning in a physics course for prospective teachers?" As indicated in Table 1, we have developed many ways to enhance listening, speaking, reading, writing, and creating and critiquing media through class activities, assignments, examinations, and a field trip to a local school. By describing activities and assignments along with some examples, we present below ways to enhance listening and speaking in physics contexts, ways to enhance reading and writing in physics contexts, ways to enhance media awareness, and ways to elicit reflections about science learning and teaching.

Enhancing Listening and Speaking in Physics Contexts

As listed in Table 1, we strive to enhance listening and speaking abilities by engaging the prospective teachers in a wide variety of class activities and assignments.

Class Activities

Passing by our lab, curious onlookers see and hear a hubbub of interaction. Class activities include articulating and interpreting positive physics learning experiences, opening topics with brainstorming, concept mapping or KWL charting, exploring phenomena in small groups, presenting findings to the whole group, coming to consensus in whole group discussions, interpreting video of children's conversations about science, role playing, and closing with a round robin of what we each have learned and are still wondering.

Table 1 Ways to integrate physics and literacy learning

Contexts	Listening	Speaking	Writing	Reading	Critiquing media
Class activities					
Articulating and interpreting positive physics learning experiences	x	x			
Opening topics with concept mapping or KWL	x	x	x		
Exploring physical phenomena in small groups	x	x	x		
Presenting findings on whiteboards to whole group	x	x	x	x	
Coming to consensus in whole group discussions	x	x			
Interpreting video of children's conversations about science	x	x			
Role playing	x	x		x	
Preparing science book talks	x	x		x	
Creating a word wall	x	x	x	x	
Articulating and using pre-/during-/post-reading strategies				x	
Responding to diagnostic questions			x		
Recording thoughts and experiences in science notebook pages			x		
Creating a website or blog summarizing findings	x	x	x	x	x
Closing with reflective writing			x		
Closing with what learned, what still wondering	x	x			
Assignments					
Reflecting on readings			x	x	
Posting on electronic bulletin board			x		
Interviewing child and adult about a topic	x	x	x		
Exploring topics with friends/family	x	x	x		
Critiquing websites			x	x	x
Writing a term paper			x	x	x
Examinations			x		x
Field trip to local school	x	x	x		

Articulating and Interpreting Positive Physics Learning Experiences Both literacy and science teacher educators emphasize the importance of opening a topic by eliciting students' relevant knowledge and experiences (Cooper and Kiger 2006; NRC 2007). In order to adapt instruction, a teacher needs to become aware of intellectual resources on which the students can build and any conceptual understandings that need refining (Smith et al. 1993; Hammer 2000). Activating prior knowledge also will help the students to make sense of the new information being developed. In addition, opening a topic by making connections with prior knowledge enables students to begin using relevant language in familiar contexts.

We activate prior knowledge about physics learning and teaching by inviting the prospective teachers to draw pictures of themselves learning physics, inside or outside of school, at any time during their lives (van Zee and Roberts 2001). The small group members talk with one another about positive experiences such as riding roller coasters, making musical instruments, or just simply swinging on swings. Next small groups introduce themselves by holding up their posters with their individual drawings and describing these experiences to the whole group. Then, they generate a list across all the groups of aspects that fostered their physics learning such as "fun, hands-on, challenged, curiosity, questioning, out of the ordinary, experiential, visual, learning with others, and motivating." This first-day activity establishes a classroom climate in which the prospective teachers begin 'speaking physics' in successful ways.

Opening Topics with Brainstorming, Concept Mapping or KWL Charting Sometimes we open a new unit by asking each small group to brainstorm together about their understanding of a concept and to create a poster as shown in Fig. 1 for the meaning of *literacy*. Or we may ask the prospective teachers to make a concept map by writing a topic, such as *light*, in the middle of a piece of chart paper and then

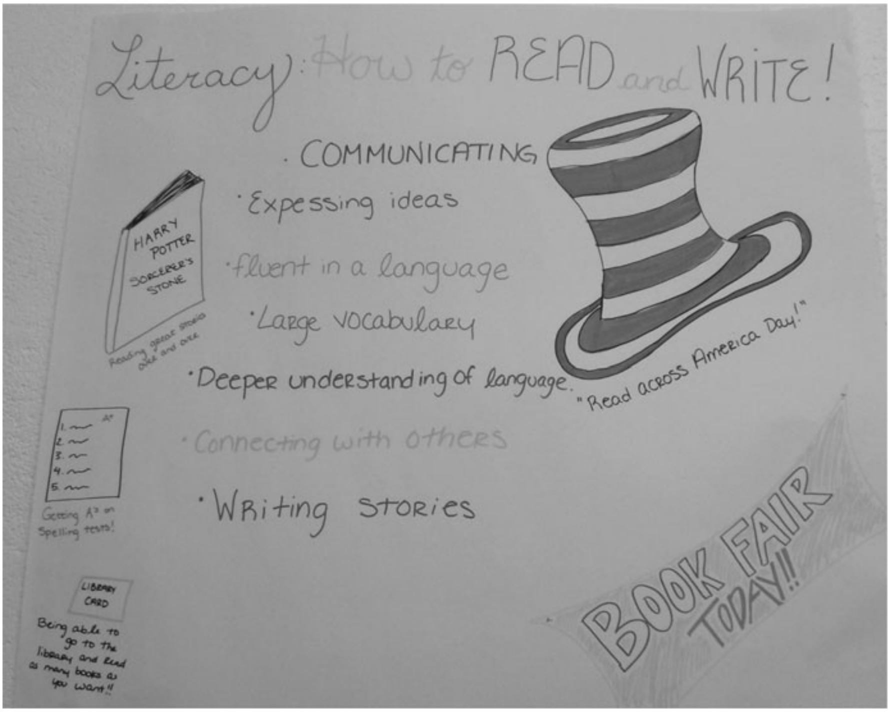


Fig. 1 Example of a small group of prospective teachers' initial understanding of the word *literacy*

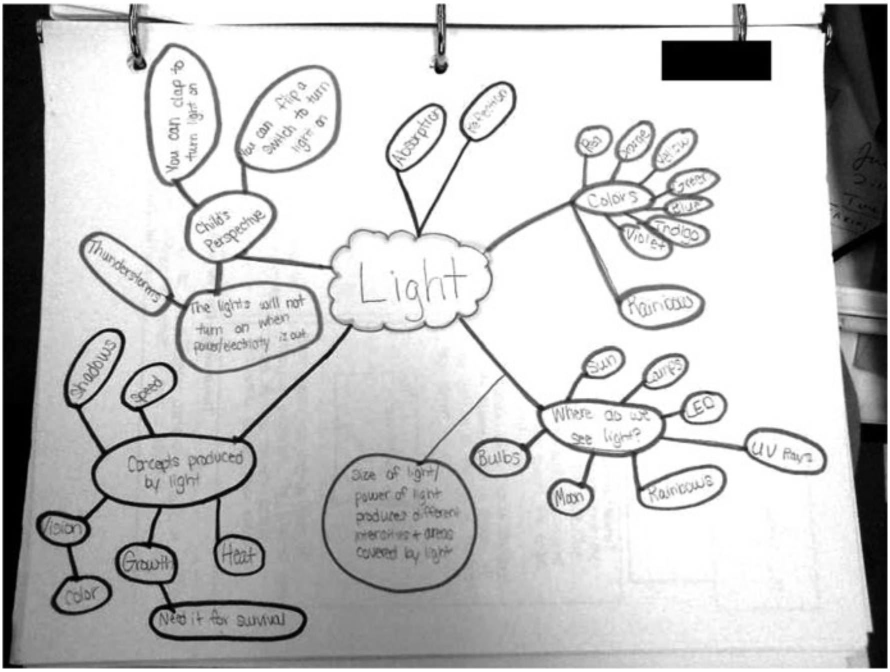


Fig. 2 Final word web for the concept of *light* by prospective teacher #6, Spring 2009

writing relevant words connected by lines that indicate relationships. This process, called concept mapping, semantic mapping, or word webbing, is recommended by both science and literacy educators (e.g., Cooper and Kiger 2006; Novak and Cañas 2006). As shown in Fig. 2, used individually as pre- and post-assessments, such concept maps can provide a visual representation of the complexity of a learner's current knowledge (White and Gunstone 1992). Used as a small group task, creating such concept maps engages group members in verbalizing and discussing what they remember and have experienced relevant to the topic. Another way to open a topic, either in small groups or as a whole group discussion, is to begin a KWL chart, a strategy adapted directly from literacy educators (Ogle 1986). First, the prospective teachers articulate what they already *K*now about the topic and what they *W*ant to learn. Near the close of the topic, they summarize what they have *L*earned.

Exploring Physical Phenomena in Small Groups, Making Presentations of Findings, and Coming to Consensus in Whole Group Discussions The prospective teachers become more comfortable 'speaking physics' as they and their group members come to understand whatever physical phenomena are the focus of their explorations (van Zee et al. 2005). They summarize their findings on large white boards and present these to the whole group. These small group presentations build confidence in 'speaking physics' in formal ways. Whole group discussions involve coming to consensus on the main ideas that have emerged from these presentations and the evidence in support of those ideas. The instructor interacts with the small groups through questions, comments, and silences (Rowe 1986; van Zee 2000) as well as facilitating these whole group discussions. This process models the emphasis on building scientific arguments and explanations advocated in national science education reform documents (NRC 1996, 2007, 2012). As the prospective teachers talk with one another about their insights and experiences, they are gaining confidence in speaking as well listening in physics contexts.

On a reflection requested mid-way in the course, one prospective teacher commented about ways that the small and whole group discussions had been fostering her learning:

> The aspect of this class that has fostered my learning the most has been the group explorations we do in class. These learning groups allow us to build up our own ideas, share them, and hear the ideas of others in a small and safe environment. I learn a lot from what others have to say in both large and small group discussions. However, I am much more likely to participate and verbalize my thoughts in a group of two or three others. It helps me to become more invested in the learning and involved in the process, which, in the long-run, also helps me to understand and remember things better.
>
> (Prospective Teacher #1, reflection on learning, Spring 2011)

However, she also conveyed some negative impressions, noting that the small group presentations seemed repetitive when all came to the same conclusions. This feedback about the course prompted an immediate change in practice. For the next topic, we asked each of the small groups to present on a different aspect of their exploration so that the small group presentations would not be repetitive of one another.

Interpreting Video of Children's Conversations About Science One way to bridge the gap between courses at the university and the reality of school classrooms is to devote some class time to watching and interpreting video of children's conversations about science (Annenberg, n.d.; Hammer and van Zee 2006). Such videos provide confirmation that thoughtful open-ended science conversations can occur even with young children, a surprise to some. The prospective teachers practice listening closely to what children are saying and gain experience in interpreting ambiguous remarks, particularly in identifying potentially useful comments which could be elaborated upon in productive ways. Reading the teacher's interpretation (Mikeska 2006) helps them envision themselves facilitating such a discussion.

Role Playing Role playing is another literacy technique (Cooper and Kiger 2006) that can be adapted by having the prospective teachers act out a discussion in which they present and argue different points of view, either spontaneously or with scripts. When we study the physics of falling objects, for example, three of the prospective teachers play the parts of Salviati, Sagredo, and Simplicio in Galileo's *Dialogue Concerning Two New Sciences* (1638/2002)

This dramatizes the logical argument Galileo presented to refute the prevailing view derived from Aristotle's writings that heavy objects fall faster than light ones. This historical example is rich in aspects prompting discussion of the nature of science. After small groups explore the issue by dropping two objects from the same height at the same time, we bring this question into the modern era by watching a videoclip of astronauts talking about Galileo while dropping a hammer and a feather on the moon (http://www.youtube.com/watch?v=5C5_dOEyAfk).

Closing with What Learned, What Still Wondering We close each session with reflective writing, during which everyone has the opportunity to record their thoughts about what has just occurred, followed by oral reflections during which everyone, including staff, comments upon what was learned and what one is still wondering about the phenomena explored or pedagogy experienced that day. Sometimes these closing thoughts generate an idea for an experiment that can be conducted at home or at the next class session. Sometimes they simply leave us with a sense of belonging to a community of physics learners, sharing interesting insights and ponderings. After exploring shadows outside and pinhole phenomena inside, for example, a prospective teacher reflected "I learned that if I form a question, I can find out the answer by exploring" and wondered "Does the moon cast shadows? What can we learn by observing the sky?"

Assignments

Some homework assignments require the prospective teachers to listen to and speak physics outside the classroom. These assignments include interviewing a child and adult about a topic, exploring physical phenomena with a friend or family member, and teaching children during a field trip to a local school.

Interviewing a Child and Adult About a Topic For each topic, we ask the prospective teachers to interview a child of the age they want to teach and an adult. They design questions to ask about the topic and post these, their interviewees' responses, and a summary on an electronic bulletin board. By reading one another's findings, they can learn about common ideas expressed on a topic. One prospective teacher noticed differences in the type of responses she was hearing:

> The adult tried to use bigger, "more sophisticated" words and sentences, whereas the child just got straight to the point and said what they (sic) wanted; they didn't try to make themselves sound smarter. The child wasn't afraid to say whatever it was they thought, even if it was wrong.
>
> (Prospective Teacher #6, interview assignment, Winter 2008)

This comment highlights an awareness of behaviors relevant to our course. Videos of class sessions show changes in the prospective teachers' ways of speaking. Later in the course, they seem less likely to try to use 'fancy' words and more willing to risk contributing whatever they are thinking in their own words to the small group and whole group discussions.

Exploring Physical Phenomena with a Friend or Family Member A graduate student assistant, a former museum educator, initiated a new assignment, exploring a topic from class with a friend or family member (Crowl 2010; Crowl et al. in press). This shifts the prospective teachers' role from learner to teacher. One articulated aspects of this shift when describing teaching her boyfriend about how big a mirror is needed for a full-length image:

> I learned through this that teaching the concept of a mirror/reflection can be very difficult to do. *There were many times that I wanted to just tell [him] the answer, but I had to bite my tongue and think of questions to help [him] think about the possibilities and understand the concept*…My boyfriend did not have any idea how this idea worked. He experimented for a while, and then we drew a ray diagram together. *I had to think of questions to get him thinking. He came to the right conclusion with my help.* The mirror would have to be half the person's height. (Emphasis added).
>
> (Prospective Teacher #1, friends/family assignment, Fall 2009)

This prospective teacher is beginning to transform her image of teaching, from telling answers to listening closely and asking responsive questions. Several prospective teachers have identified the friends and family assignments as the aspect of the class that fostered their learning the most.

Field Trip to a Local School Toward the end of the course, we go to a local school to teach one of the topics that we have been exploring in class. Each prospective teacher gains experience teaching science with a small group of the children. They learn the physics content in a deeper way as well as listening and speaking physics in a setting that matches their aspirations. One wrote a reflection about teaching a small group of fifth-grade students about pinhole cameras:

> We spent over an hour teaching about pinhole cameras and the phenomena that occur…It was amazing to see the excitement of the students to explore and discover the pinhole phenomena …(they) proceeded to move the light bulb around, flip the light bulb upside down, turn their head upside down, turn the light bulb sideways, etc.… Throughout all of my life, I was always under the impression that the teacher must impart knowledge on the students by preaching to them…I realized, though, through this classroom experience, that students are fully capable of discovering phenomena and coming to conclusions … Given the right tools, students can do anything. I think this classroom experience helped me discover that I can run an inquiry-based discovery classroom.
>
> (Prospective Teacher #2, reflection on school visit, Spring 2011)

For many, this is their first experience teaching. Our hope is that they begin forming an identity as teachers who enjoy science and who engage their students in exploring natural phenomena.

Enhancing Reading and Writing in Physics Contexts

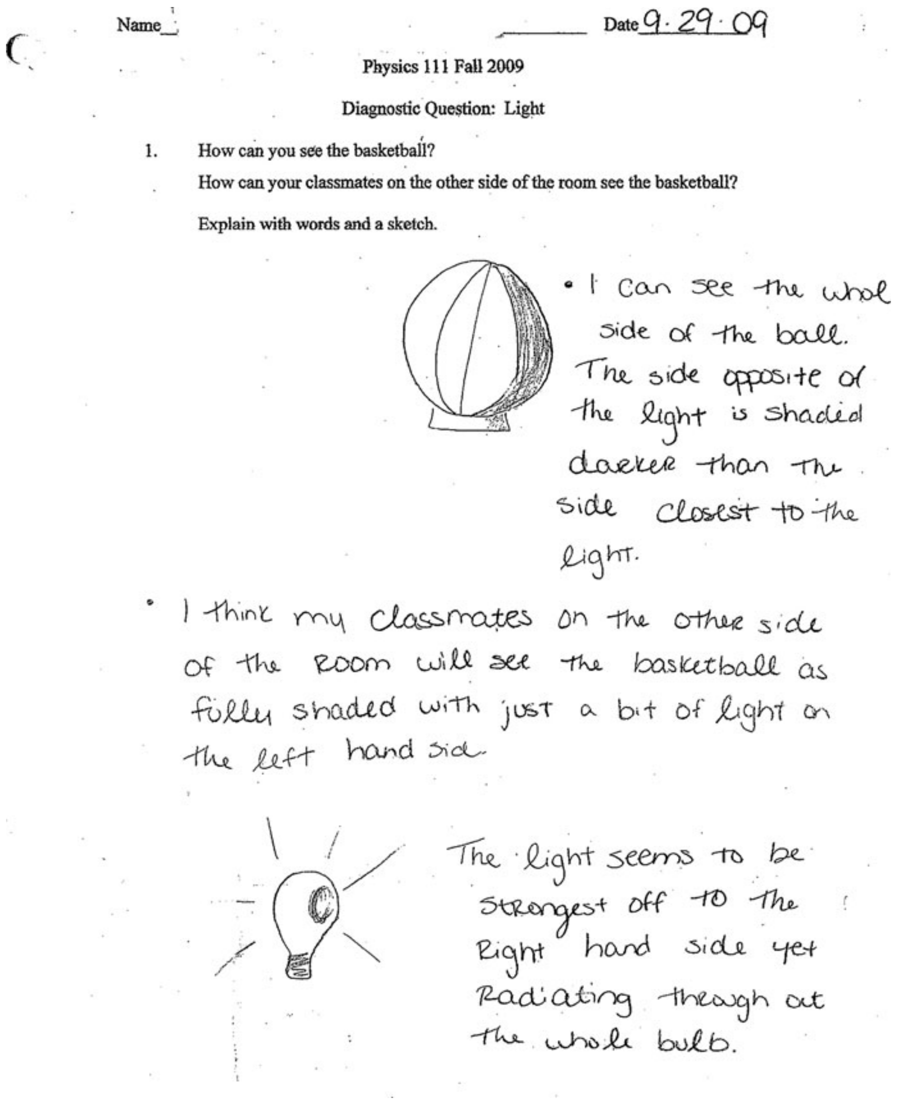
As listed in Table 1, we also have developed a variety of ways to enhance reading and writing abilities through class activities and assignments. We describe these below.

Class Activities

We strive to enhance the prospective teachers' reading and writing abilities by engaging them in explicitly using literacy strategies, responding to diagnostic questions, recording thoughts and experiences in science notebook pages, creating a website or blog summarizing findings, and closing with reflective writing.

Explicitly Using Literacy Strategies Such as Interactive Book Talks, Word Walls, and Pre-, During-, and Post-Reading Strategies Once a week we open class with explicit attention to using literacy strategies in physics contexts. A graduate student assistant, a former elementary special education teacher, facilitated activities such as giving interactive book talks using a variety of relevant children's books (Devitt 2010; http://contentbuilder.merlot.org/toolkit/html/stitch.php?s=68418716982397). He also introduced making a word wall for relevant science words (Brabham and Villaume 2001). These opening sessions also focused on pre-, during-, and post-reading strategies (Cooper and Kiger 2006; Readence et al. 2000). What, for example, can readers do to set a purpose for reading before they begin, particularly if the text looks challenging? During reading, how can they make sense out of new vocabulary in this context? Revise or generate new predictions and questions based on what they are learning? After reading, what can they do to remember the new information presented and to form a purpose for seeking additional resources? Such explicit conversations about reading strategies, grounded in materials related to topics we study in the course, apparently have enhanced reading experiences even in other classes, according to some of the prospective teachers' reflections on changes they have experienced through this course.

Responding to Diagnostic Questions The importance of writing to learn has been documented in many contexts (Bangert-Drowns et al. 2004; Ellis 2004; Klein 2000). We start many topics with diagnostic questions, for example, to document the prospective teachers' initial ideas (Minstrell 2000). Then, they revisit the same questions later to document and interpret their own progress. We begin the study of light, for example, with a diagnostic question about how one is able to see a basketball in a dark room lit by a single lamp and how another person in the room also could see the ball. As shown in Fig. 3a, the prospective teachers often simply draw a ball and lamp. Typically, they draw lines radiating from the lamp, an intuitive beginning of a ray diagram. If they include a person, they typically put an arrow from the person's eye to the ball, a visual representation of 'looking at' the ball. A few words describe, rather than explain, what they see. Later responses are more detailed. As shown in Fig. 3b, this prospective teacher sketched the situation


Name_ Date 9·29·09

Physics 111 Fall 2009

Diagnostic Question: Light

1. How can you see the basketball?
How can your classmates on the other side of the room see the basketball?
Explain with words and a sketch.

• I can see the whole side of the ball. The side opposite of the light is shaded darker than the side closest to the light.

• I think my classmates on the other side of the room will see the basketball as fully shaded with just a bit of light on the left hand side.

The light seems to be strongest off to the right hand side yet radiating through out the whole bulb.

Fig. 3 **a** Example of prospective teacher #6′s initial response to diagnostic question, Fall 2009. **b** Example of prospective teacher #6′s later response to the diagnostic question, Fall 2009

with a lamp, basketball, and person, wrote statements about five relevant powerful ideas about light, drew a diagram with at least one continuous ray going from the light bulb to the ball to an eye, and then applied powerful ideas about light in writing a coherent explanation about how she was seeing the ball. Responding to this diagnostic question is the first step in building an explanatory model for the phases of the moon. Although many of the prospective teachers initially attribute the moon’s changing phases to the moon being in the earth’s shadow, they come to realize that the dark portion of the moon is due to the moon itself blocking light

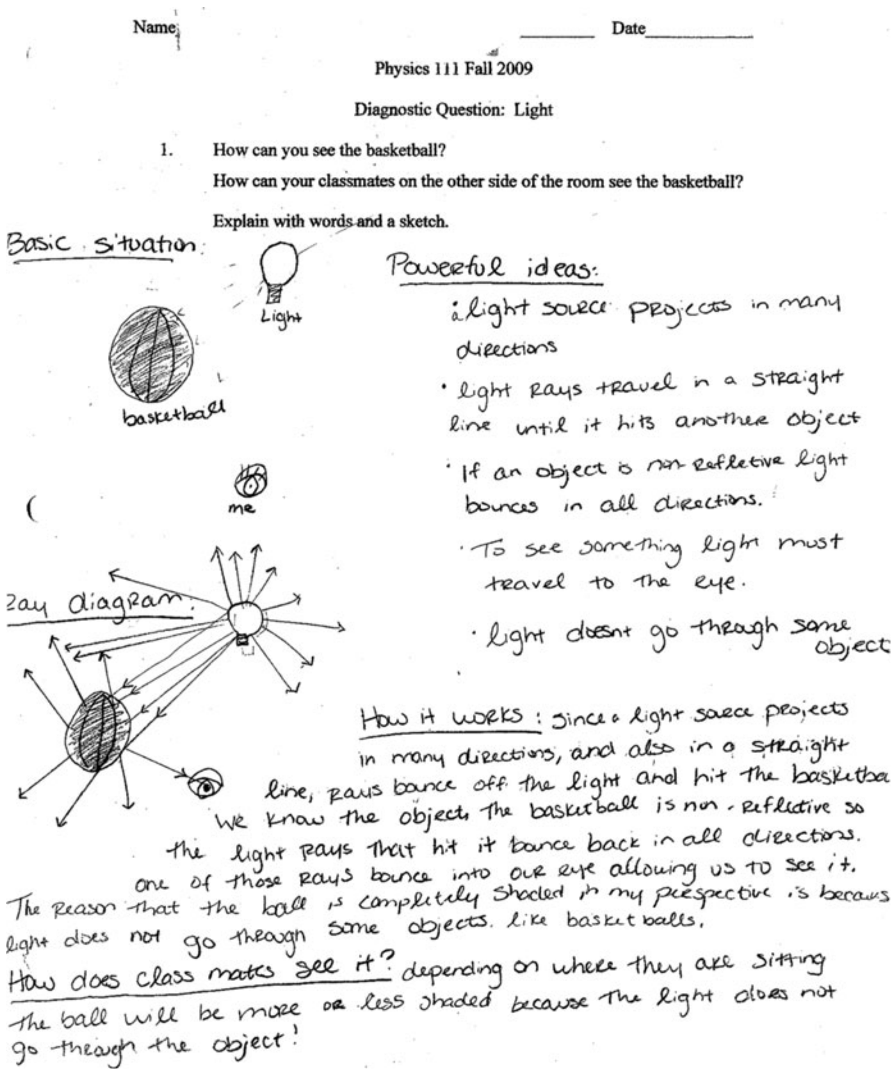


Fig. 3 continued

from the sun, just as the dark portion of the ball is due to the ball itself blocking light from the lamp. This is an example of using analogies as bridges in building understanding of concepts in more abstract contexts (Clement 1993, 2008).

Recording Thoughts and Experiences in Science Notebook Pages We encourage the prospective teachers to keep track of what they are wondering, thinking, and doing on science notebook pages (Devitt 2010). The front of each page has areas for recording questions, observations, and new vocabulary; the back provides space for summarizing the powerful ideas developed and evidence supporting those ideas as

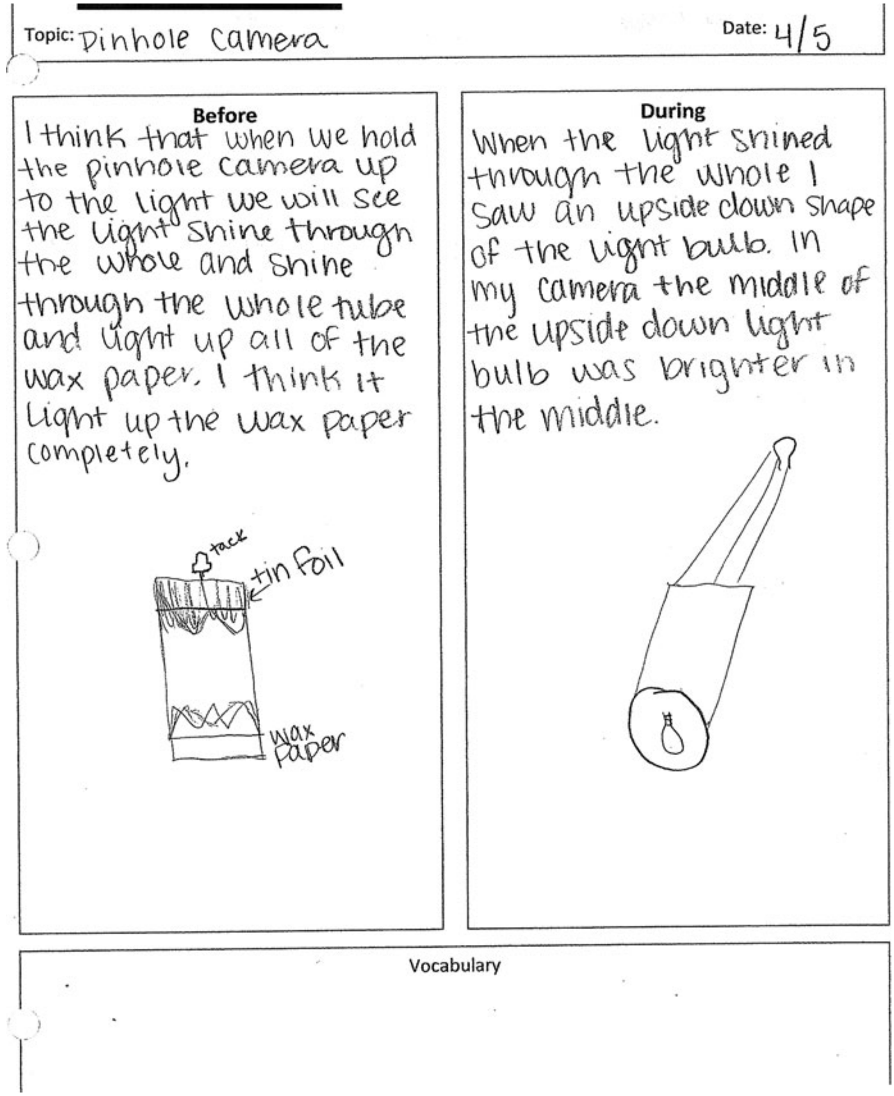
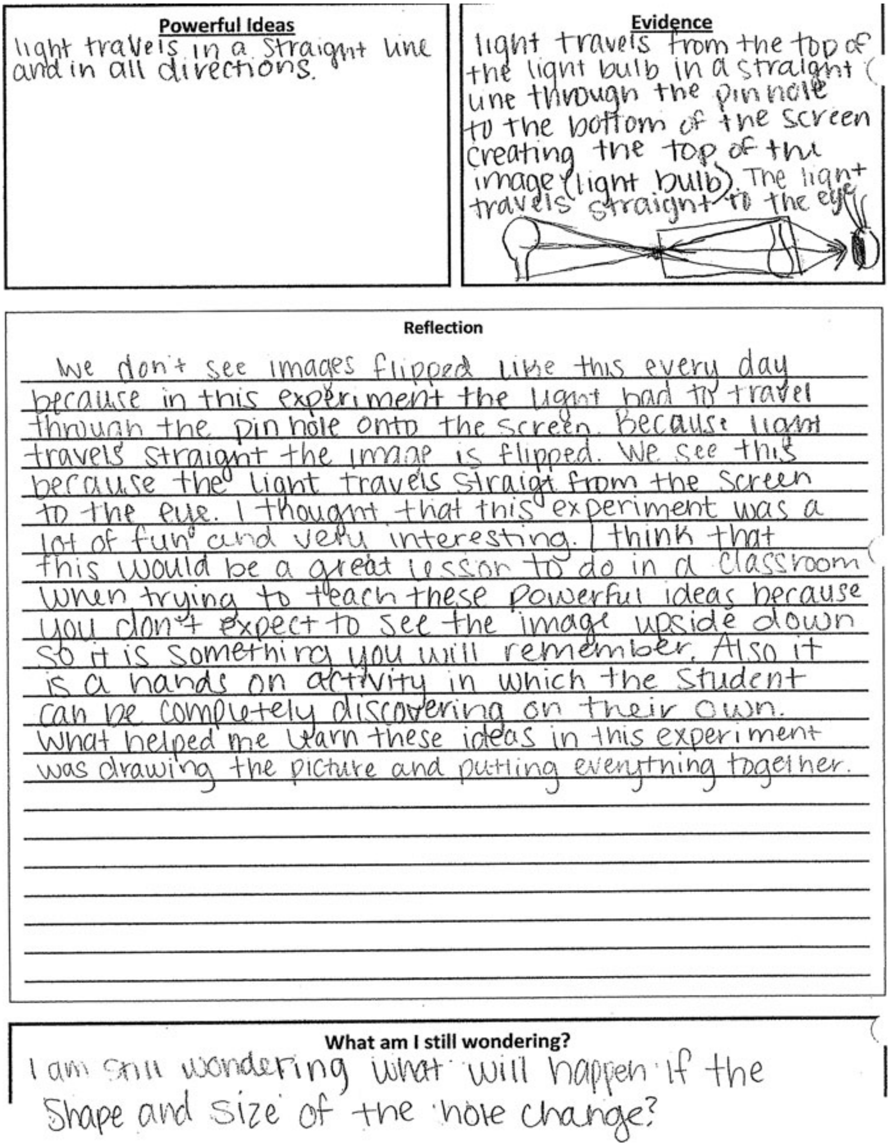


Fig. 4 **a** Example of front of prospective teacher #5′s science notebook page for session on pinhole phenomena, Spring 2010. **b** Example of back of prospective teacher #5′s science notebook page, Spring 2010

well as reflective writing about what happened that day and current wonderings. This page is a progress report recording current understandings. The page shown in Fig. 4, for example, shows an initial ray diagram for a pinhole camera. The prospective teacher represented a light ray by drawing a continuous line from her sketch of the top of the light bulb to her sketch of the top of the upside down bulb on the screen. The detailed explanation tracing the path of a particular ray emerged,



Powerful Ideas

light travels in a Straight line and in all directions.

Evidence

light travels from the top of the light bulb in a straight line through the pin hole to the bottom of the screen creating the top of the image (light bulb). The light travels straight to the eye

Reflection

We don't see images flipped like this every day because in this experiment the light had to travel through the pin hole onto the screen. Because light travels straight the image is flipped. We see this because the light travels straight from the screen to the eye. I thought that this experiment was a lot of fun and very interesting. I think that this would be a great lesson to do in a classroom when trying to teach these powerful ideas because you don't expect to see the image upside down so it is something you will remember. Also it is a hands on activity in which the student can be completely discovering on their own. What helped me learn these ideas in this experiment was drawing the picture and putting everything together.

What am I still wondering?

I am still wondering what will happen if the Shape and size of the hole change?

Fig. 4 continued

with guidance from staff, during joint construction on a large whiteboard for a small group's presentation.

One of the prospective teachers commented upon ways in which writing the notebook pages had fostered her learning:

> This class is very different from other science classes that I have taken because it is focused on exploration and building ideas in our own ways rather than on

> taking notes and filling out worksheets. The notes we take and papers we fill out are open-ended enough that we can interpret the information we learn or are given in a way that makes sense to us. We aren't copying exactly what the teacher writes or filling in a missing word in a sentence about what we just learned; we are recording things in our own ways and using them as reference materials as we need to.
>
> (Prospective Teacher #1, reflection on course, Spring 2011)

Creating a Website or Blog Summarizing Findings As part of our study of a topic, members of each small group work together to create a website or blog summarizing their findings. Each small group has a digital camera to take photos and make video clips of their explorations. They work together in class to write descriptions of what these show and what they learned. In addition to serving as resources for review before exams, the URLs for these websites can be emailed to friends and family members, perhaps initiating additional experiences in writing and talking about physics in response to any questions their friends or family members pose. See, for example, http://contentbuilder.merlot.org/toolkit/html/snapshot.php?id=48464235615418. In this website, *Exploring the Nature of Light*, a small group of students present their findings from investigations that we derived from several sources. In the left panel, they present evidence for the powerful idea that light leaves a source in all directions. This follows opening lessons in the American Association of Physics Teachers' *Powerful Ideas in Physical Science: Light and Color* (2001). The making of a sun plot, shown in the middle panel, draws from the astronomy materials in *Physics by Inquiry* (McDermott, L. C. and the Physics Education Group 1996). Their exploration of pinhole phenomena, reported in the right panel, used online directions for making a pinhole camera, (http://www.exploratorium.edu/IFI/activities/pinholeinquiry/viewer.html), provided by a science museum. The structure of their explanation shows the emphasis we adapted from *Physics and Everyday Thinking* (Goldberg et al. 2008) on explicitly stating physics principles and applying them in writing explanations.

Closing with Reflective Writing As noted above, we close each class with at least 10 min for quiet writing about what one has learned during the session and what still wondering. We follow this with a brief comment by each student and staff member to close the session.

Assignments

Homework assignments and examinations also foster development of reading and writing abilities. These include reflecting on readings, posting on an electronic bulletin board, writing a formal paper, and responding to examination questions.

Reflecting on Readings The prospective teachers read and reflect upon a variety of documents in physics contexts. These include papers written by teachers about engaging children in similar contexts to those we are studying in class, such as

Hogan's account (2007) of addressing a first grade literacy objective, writing clear sequential directions, while using motion detectors with her students. Readings also include excerpts from historical writings, such as Galileo's dialogue (1638/2002) about falling objects, as well as relevant excerpts from physics textbooks and news items. Each reading assignment includes explicit use of one or more of the pre-, during-, and post- reading strategies taught in class. One version includes articulating three questions: what the reader would ask the author if that were possible, what the reader would ask colleagues to launch a discussion of the paper, and what the reader is wondering having now read and thought about the issues presented.

Posting on an Electronic Bulletin Board The homework assignments provide many opportunities for writing about physics in informal ways. As noted above, the prospective teachers post findings on an electric bulletin board after interviewing friends and/or family members or engaging them in explorations about a topic we are studying in class.

Writing a Formal Paper Near the end of the course, the prospective teachers also write a formal paper that reports their observations of the sun and the moon, patterns in these observations, and the explanatory model we develop. They use evidence from their responses to various diagnostic questions to discuss changes in their thinking about the phases of the moon, the nature of scientific explanations, and inquiry approaches to teaching and learning. In commenting upon this writing experience, Prospective Teacher #1 in the Spring 2009 course noted, "I found that I had so much to say and I actually kind of enjoyed writing parts of it. I had fun adding different charts and diagrams and I think for the first time in my [freshman] college year I actually wrote more than the minimum requirement of pages!"

Responding to Examination Questions The last assignments before the mid-term and final examinations invite the prospective teachers to propose questions. They post their questions on the electronic bulletin board so all can review by working through these possible exam items. Typically, about half of the exam questions derive from these suggestions, with some editing. The mid-term and final examinations are open-notebook and involve writing explanations rather than solving equations. We attempt to situate these in classroom settings and to include aspects of science pedagogy as well. Here, for example, is a question about the phases of the moon:

> One of the students in your classroom tells you, the teacher, "The last time I saw it, the moon was lit on the left. But just last night, I saw the moon and it was lit on the right side. Why did it flip-flop on me?" Explain in words and drawings the physics underlying the student's two observations. Then state the age of your student and consider, how would you respond to this student's question?

The exams also may include critiquing the scientific accuracy of a sample of children's literature.

Enhancing Media Awareness in Science Contexts

One of our goals is to prepare prospective teachers to recognize the need to critique children's books and other media for scientific accuracy. Near the end of the moon studies, for example, an assignment asks them to find and critique websites that purport to explain the moon's changing phases. One prospective teacher found a website that had a reasonable explanation of the moon's phases but provided a religious explanation for its origin. The prospective teachers also critique children's books such as a popular one that shows a gibbous moon shaped like a cookie with a bite out of it and labels this a three-quarter moon (Asch 1978).

Eliciting Reflections on Learning and Teaching

Midway in the Spring 2011 course, we asked the prospective teachers for reflections on aspects of the course that had fostered their learning, or not, ways the course differed from other science courses they had taken, and changes in their views about learning and teaching. Near the end of the course, we asked the prospective teachers to rate their impressions of changes in their interest in science and intended teaching practices as well was their opinions about various course components. We asked these questions to direct attention explicitly to issues of teaching and learning as well as to gather evidence of their perceptions of the course.

Aspects that Foster Learning the Most

Almost all the prospective teachers mentioned exploring phenomena and working with peers. One wrote, for example,

> I've really enjoyed "playing" in this class so far because it gives me the chance to predict what I think will happen during an activity and then to explore for myself what actually will happen during the activity. I also enjoy the opportunities we get to have somewhat of a science fair where each group gets to explain their predictions and findings. It helps because each group member has to talk and explain a part of the findings, which gives me practice on how to explain things.
>
> (Prospective Teacher #12, reflection on learning, Spring 2011)

Some mentioned the emphasis on crafting explanations in terms of the homework:

> The homework allows me to fine tune my physics thinking and language. By performing multiple repetitions on problems, I get more comfortable solving the problems as well as improve my language to become extremely clear.
>
> (Prospective Teacher #13, reflection on learning, Spring 2011)

Also mentioned was exploring phenomena with friends and family members.

Aspects Foster Learning the Least

Five of the fifteen mentioned the repetitiveness of the group presentations, which prompted our change in practice to vary each group's focus. Mentioned twice were the repetitiveness of some homework questions, creation of the websites, reflections on the readings, and the sky journals to record observations of the moon. A well-prepared prospective middle school teacher noted how simplistic the course seemed, whereas a prospective early childhood teacher described having a hard time with aspects directed toward those planning to teach in middle schools. Another mentioned hesitating to ask questions, which resulted in our making an extra effort to be more supportive and encouraging. A senior, graduate of a science teaching methods course, wanted better connections to her future teaching career such as lesson plans and explicit mention of relevant standards and children's books.

Comparison to Other Science Courses

Most of the prospective teachers mentioned that lectures were typical of other courses. One explained the differences as follows:

> Other science classes we had a lecture and a lab. There was minimal group work; you work with a partner at the most. The instructors weren't too keen on figuring things out for yourself; it was more of memorizing and learning the information out of the book or in lab where they told you what to do. In this class we get to problem solve in groups and have a bit of fun with science which I have never really experienced anywhere else.
>
> (Prospective Teacher #7, reflection on learning, Spring 2011)

A recurring theme was being able to share ideas rather than being told what to think.

Changes in Views About Science Teaching and Learning

The prospective teachers' typical anxiety when they enter the course seems to ease. One, for example, wrote:

> The first five weeks of this course have really opened my eyes about what you can do with science in a classroom. After all of my previous science class experiences as a student I think science was probably one of the subjects I feared having to teach the most. I didn't feel confident in my own scientific knowledge and didn't know how to make it interesting to my students. Experiences in this class have gotten me very excited about teaching science and using student interests to guide the curriculum and learning. The methods we have used have shown me new ways to lead experiments and lessons as well as incorporate multiple subjects, like literacy and math, into science on a regular basis.
>
> (Prospective Teacher #1, reflection on learning, Spring 2011)

Another theme in these reflections was the perception that science can be the focus for learning:

Table 2 Prospective teachers' ratings on end-of-course questionnaire

Item rated from 1 to 5	N	Mean	Median	Mode	Range
Initial interest in science	10	2.3	2	2	1–3
Current interest in science	10	3.3	3.5	4	2–4
Initial likelihood of teaching science through inquiry	10	2.2	2	2	2–4
Current likelihood of teaching science through inquiry	11	4.8	4	4	4–5
Initial likelihood of integrating science and literacy learning	13	1.8	1.5	1	1–4
Likelihood of integrating science and literacy learning	13	4.5	5	5	5
Teaching at elementary school	13	4.6	5	5	3–5
Learning about literacy strategies	13	4.1	4.5	5	1–5
Friends and family assignments	13	3.8	4	4 and 5	2–5
Reflecting about what learned, what wondering at the end of class	13	3.1	3	3	1–5
Moon unit	13	4.4	5	5	2–5
Light unit	13	4.1	4	5	2–5
Heat and temperature unit	13	3.6	4	3 and 5	1–5
Motion unit	13	3.1	3	3	1–5

> These first five weeks of this course have had an influence on the way I think about teaching and learning, especially for science. In the younger grades teachers can implement other things into science, such as new vocabulary, reading, writing and crafts. Before when I thought about science for elementary school I thought we would do one experiment and be done, but now I understand that a science topic can be the center of your classroom for all other subjects.
>
> (Prospective Teacher #9, reflection on learning, Spring 2011)

Shift in Interest in Science and Intended Teaching Practices

As shown in Table 2, the prospective teachers rated the extent of their interest in science for before this course and at the end of the course from 1 (not interested) to 5 (interested). Excluding three who rated options at 5′s for both before and at the end of the course, a paired t test indicated a statistically significant increase in the means, from 2.3 to 3.3 at $p < .001$. They also rated the likelihood they would teach science through inquiry, for before this course and at the end of the course, from 1 (not likely) to 5 (likely). A paired t test indicated a statistically significant increase in the means, from 2.2. to 4.8, at $p < .001$. Similarly they rated the likelihood they would integrate science and literacy learning in their own classrooms. A paired t test indicated a statistically significant increase in the means, from 1.8 to 4.5, at $p < .001$.

Interest and Usefulness of Course Components

Although we thought there might be a difference in the prospective teachers' perceptions of their interest in and the usefulness of various activities and assignments, these ratings were too similar to distinguish and we report just one value for each question. The highest rated activity was teaching at the elementary school (mean, 4.6). Learning about literacy strategies was well regarded (mean, 4.1). Doing the friends and family assignments was somewhat well regarded (mean, 3.8). Both were controversial, however, receiving median and mode ratings of 4 and 5 but some low ratings of 1 and 2, respectively. Closing class with oral reflections was controversial with range 1–5 and mean of 3.1. The moon unit was highly rated (mean, 4.6), with positive views of learning in that context about the nature of scientific explanations (mean, 4.2) and about inquiry teaching and learning (mean, 4.2). Also well regarded was the light unit (mean, 4.1). The unit on heat and temperature was somewhat accepted (mean, 3.6). The motion unit, rushed at the end of the course, was tolerated (mean, 3.1).

Limitations

This has been a progress report on an evolving effort to engage prospective teachers in integrating science and literacy learning in a physics course under development. The prospective teachers' comments on the mid-course reflections were not anonymous and therefore may have been overly positive. Responses on the end-of-course survey were anonymous but provided limited information as ratings; few wrote comments. Many aspects of our own learning have been omitted as well as discussion of our collaborative process. Space limitations also have prevented presentation of detailed evidence of the prospective teachers' learning during the course. The biggest limitation is that we have no information about the eventual outcome: will integrating physics and literacy learning in this course impact the way these prospective elementary and middle school teachers actually teach science? We need to follow them into the classroom to see whether they choose to integrate science and literacy learning with their own students.

Implications

This project contributes to the literature on integrating science and literacy learning (Anthony et al. 2010; Douglas et al. 2006; Saul 2004). We described a physics course designed to prepare prospective elementary and middle school teachers to engage students in exploring and explaining physical phenomena, and while doing so, to enhance students' abilities to listen closely, speak clearly, read with comprehension, write coherently, and create and critique multi-media resources competently in science contexts.

Implicit modeling of literacy learning occurs in many physics courses that emphasize student discussions. Faculty who practice *peer instruction* (Mazur 1997), for example, already provide opportunities for students to speak physics with one another as well as listen to lectures. Using such *interactive engagement* techniques in a lecture course seems to increase the effectiveness of physics instruction (Crouch and Mazur 2001; Hake 1998; Meltzer and Manivannan 2002). Encouraging interactive engagement outside of class also would enhance learning. An easy way to do this would be to make assignments that involve students in interviewing friends and/or family members about the topic currently presented in class and engaging them in exploring that topic with simple equipment likely to be found at home (Crowl 2010; Crowl et al. in press). Emphasis would be placed on listening closely to what was said and asking questions to elicit clarifications and justifications. Students could post their findings on an electronic bulletin board for a small amount of credit with little extra work for the instructor as such informal writing would not need to be formally assessed for content. Such postings also could provide useful information for the instructor about ways to make connections among topics in the course and everyday life, ideas that individuals new to physics may generate when prompted, and intellectual resources that the students may be able to build upon if utilized.

Explicit modeling of literacy techniques could be integrated into all physics instruction. Introducing pre-, during-, and post-reading strategies in large lecture courses could help students learn how to make better use of their textbooks and associated materials. Even just personal stories about how the faculty member approaches reading challenging technical materials could be helpful. Explicitly requiring students to read and respond to questions before class supports peer instruction during lecture and can alert faculty to difficulties that need to be addressed (Crouch and Mazur 2001). Faculty also could assign students to critique relevant blogs and websites to learn by accessing a variety of presentations on a topic (Duda and Garrett 2008).

Increasing formal writing opportunities can be problematic, given the extra work needed for assessment. However, faculty can encourage students to approach typical physics problems systematically by sketching the situation, reviewing and writing relevant physics principles, drawing appropriate visual representations, and explicitly using the relevant physics principles to explain their analyses of the situation before undertaking mathematical calculations.

Integrating physics and literacy learning can help students, including prospective secondary teachers enrolled in the standard physics courses, perceive science to be an ideal context to foster learning across the disciplines. That is the long-term objective of this collaborative project.

Acknowledgments This project is supported by National Science Foundation grant No. 0633752-DUE, Integrating Physics and Literacy Learning in a Physics Course for Elementary and Middle School Teachers, Henri Jansen, PI, Department of Physics, Emily van Zee, co-PI, Department of Science and Mathematics Education, College of Science and Kenneth Winograd, co-PI, Department of Teacher and Counselor Education, College of Education, Oregon State University.

References

American Association of Physics Teachers. (2001). *Powerful Ideas in physical science*. College Park, MD: AAPT.

American Association of Physics Teachers and American Physical Society. (n.d.). *PhysTEC (Physics Teacher Education Coalition).* Retrieved from http://www.phystec.org/components/elementary-teachers/index.php.

Annenberg Foundation. (n.d.) *Teacher professional development and classroom resources across the curriculum: Science*. Retrieved from www.learner.org.

Anthony, R. J., Tippett, C. D., & Yore, L. D. (2010). Pacific CRYSTAL Project: Explicit literacy instruction embedded in middle school science classrooms. *Research in Science Education, 40*, 45–64.

Asch, F. (1978). *Moon bear*. New York: Scribner.

Bangert-Drowns, R. L., Hurley, M. M., & Wilkinson, B. (2004). The effects of school-based writing-to-learn interventions on academic achievement: A meta-analysis. *Review of Educational Research, 74*(1), 29–58.

Brabham, E. G., & Villaume, S. K. (2001). Building walls of words. *The Reading Teacher, 54*(7), 700–702.

Century, J. R., Flynn, J., Makang, D. S., Pasquale, M., Robblee, K. M., Winokur, J., et al. (2002). Supporting the science-literacy connection. In R. W. Bybee (Ed.), *Learning science and the science of learning*. Arlington, VA: NSTA Press.

Cervetti, G., Pearson, P. D., Bravo, M. A., & Barber, J. (2006). Reading and writing in the service of inquiry-based science. In R. Douglas, M. Klentschy, & K. Worth (Eds.), *Linking science and literacy in the K-8 classroom* (pp. 221–244). Arlington, VA: NSTA Press.

Clement, J. (1993). Using bridging analogies and anchoring intuitions to deal with students' preconceptions about physics. *Journal of Research in Science Teaching, 30*(10), 1241–1257.

Clement, J. (2008). *Creative model construction in scientists and students: The role of imagery, analogy, and mental simulation*. Dordrecht: Springer.

Cochran-Smith, M., & Lytle, S. (1993). *Inside outside: Teacher research and knowledge*. New York: Teachers College Press.

Cooper, J. D., & Kiger, N. D. (2006). *Literacy: Helping children construct meaning* (6th ed.). Boston: Houghton Mifflin.

Crouch, C., & Mazur, E. (2001). Peer instruction: Ten years of experience and results. *American Journal of Physics, 69*(9), 970–977.

Crowl, M. (2010). *Friends and family: One strategy for connecting the classroom with the real world. (Master's thesis)*. Retrieved from http://hdl.handle.net/1957/15850.

Crowl, M., Devitt, A., Jansen, H., van Zee, E., & Winograd, K. (in press). Encouraging prospective teachers to engage friends and family in exploring physical phenomena. *Journal of Science Teacher Education*. doi:10.1007/s10972-012-99310-3.

Devitt, A. (2010). *Implementing science notebooks and reading strategies in a physics course for prospective elementary and middle school teachers. (Master's project)*. Retrieved from http://contentbuilder.merlot.org/toolkit/html/stitch.php?s=68418716982397.

Douglas, D., Klentschy, M. P., Worth, K., & Binder, W. (2006). *Linking science and literacy in the K-8 classroom*. Arlington, VA: National Science Teachers Association Press.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*(3), 287–312.

Duda, G., & Garrett, K. (2008). Blogging in the physics classroom: A research-based approach to shape students' attitudes toward physics. *American Journal of Physics, 76*(11), 1054–1065.

Ellis, R. (2004). University students' approaches to learning science through writing. *International Journal of Science Education, 26*, 1835–1853.

Galilei, G. (1638/2002). *Dialogue concerning two new sciences* (pp. 47–50). Philadelphia: Running Press.

Gallas, K. (1995). *Talking their way into science: Hearing children's questions and theories and responding with curricula*. New York: Teachers College Press.

Goldberg, F., Robinson, S., & Otero, V. (2008). *Physics and everyday thinking*. Armonk, NY: It's About Time, Heff Jones Education Division.

Greenleaf, C., Schoenbach, R., Cziko, C., & Mueller, F. (2001). Apprenticing adolescent readers to academic literacy. *Harvard Educational Review, 71*(1), 79–129.

Guthrie, J., Wigfield, A., Barbosa, P. P., Perencevich, K. C., Taboada, A., Davis, M. H., et al. (2004). Increasing reading comprehension and engagement through concept-oriented reading instruction. *Journal of Educational Psychology, 96*, 403–423.

Hake, R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66*(1), 64–74.

Hammer, D. (2000). Student resources for learning introductory physics. *American Journal of Physics, 68*(S1), S52–S59.

Hammer, D., & van Zee, E. (2006). *Seeing the science in children's thinking*. Portsmouth, NH: Heinemann.
Hestenes, D. (1987). Toward a modeling theory of physics instruction. *American Journal of Physics, 55*(5), 440–454.
Hogan, K. (2007). How can playing with a motion detector help children learn to write clear sequential directions? In D. Roberts, C. Bove, & E. van Zee (Eds.), *Teacher research: Stories of learning and growing* (pp. 2–9). Arlington, VA: National Science Teachers Association Press.
Jansen, H., van Zee, E. H., & Winograd, K. (2006). *Integrating physics and literacy instruction in a physics course for prospective elementary and middle school teachers*. National Science Foundation grant NO. No. 0633752-DUE.
Kelly, G. J. (2007). Discourse in science classrooms. In S. Abell & N. Lederman (Eds.), *Handbook of research on science education*. New York: Routledge.
Klein, P. D. (2000). Elementary students' strategies for writing-to-learn in science. *Cognition and Instruction, 18*(3), 317–348.
Laws, P. W. (2004). *Workshop physics activity guide* (2nd ed.). New York: Wiley.
Lee, O., Deaktor, R. A., Hart, J. E., Cuevas, P., & Enders, C. (2005). An instructional intervention's impact on the science and literacy achievement of culturally and linguistically diverse elementary students. *Journal of Research in Science Teaching, 41*(10), 1021–1043.
Lemke, J. (1990). *Talking science: Language, learning and values*. Norwood, NJ: Ablex.
Loughran, J. (2007). Researching teacher education practices: Responding to the challenges, demands, and expectations of self-study. *Journal of Teacher Education, 58*(12), 11–21.
Mazur, E. (1997). *Peer instruction: A user's manual*. Upper Saddle River, NJ: Prentice Hall.
McDermott, L. C. (1990). A perspective on teacher preparation in physics and other sciences: The need for special science courses for teachers. *American Journal of Physics, 58*, 734–742.
McDermott, L. C. (2006). Preparing K-12 teachers in physics: Insights from history, experience, and research. *American Journal of Physics, 74*(9), 758–762.
McDermott, L. C. and the Physics Education Group. (1996). *Physics by Inquiry*. New York: Wiley.
Meltzer, D. E., & Manivannan, K. (2002). Transforming the lecture-hall environment: The fully interactive physics lecture. *American Journal of Physics, 70*(6), 639–654.
Mikeska, J. (2006). Falling objects. In D. Hammer & E. H. van Zee (Eds.), *Seeing the science in children's thinking* (pp. 72–83). Portsmouth, NH: Heinemann.
Minstrell, J. (2000). Student thinking and related assessment: Creating a facet assessment-based learning environment. In J. Pellegrino, L. Jones, & K. Mitchell (Eds.), *Grading the nation's report card: Research from the evaluation of NAEP*. Washington, DC: National Academies Press.
National Research Council. (1996). *National science education standards*. Washington, DC: National Academies Press.
National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: National Academies Press.
National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.
Novak, J. D., & Cañas, A. J. (2006). The origins of the concept mapping tool and the continuing evolution of the tool. *Information Visualization, 5*(3), 175–184.
Ogle, D. M. (1986). K-W-L: A teaching model that develops active reading of expository text. *The Reading Teacher, 39*(6), 564–570.
Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science, 328*, 463–466.
Pearson, P. D., Raphael, T. E., Benson, V. L., & Madda, C. L. (2007). Balance in comprehensive literacy instruction: Then and now. In L. B. Gambrell, L. M. Morrow, & M. Pressley (Eds.), *Best practices in literacy instruction*. New York: Guilford Publications, Inc.
Readence, J. E., Moore, D. W., & Rickelman, R. J. (2000). *Prereading activities for content area reading and learning* (3rd ed.). Newark, DE: International Reading Association.
Roth, K. (2007). Teachers as researchers. In S. Abell & N. Lederman (Eds.), *Handbook of research on science education*. New York: Routledge.
Rowe, M. B. (1986). Wait time: Slowing down may be a way of speeding up! *Journal of Teacher Education, 37*(1), 43–50.
Saul, W. (Ed.). (2004). *Crossing borders in literacy and science instruction: Perspectives on theory and practice*. Arlington, VA: NSTA Press and Newark, DE: International Reading Association.

Shulman, L. (2004). *Teaching as community property: Essays on higher education*. San Francisco: Jossey-Bass.

Smith, J. P., diSessa, A. A., & Roschelle, J. (1993). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *The Journal of the Learning Sciences, 3*(2), 115–164.

Ukens, L., Hein, W. W., Johnson, P. A., & Layman, J. (2004). Powerful ideas in physical science. *Journal of College Science Teaching, 33*(7), 38–41.

van Zee, E. H. (2000). Analysis of a student-generated inquiry discussion. *International Journal of Science Education, 22*, 115–142.

van Zee, E. H., Hammer, D., Bell, M., Roy, P., & Peter, J. (2005). Learning and teaching science as inquiry: A case study of elementary school teachers' investigations of light. *Science Education, 89*, 1007–1042.

van Zee, E. H., & Roberts, D. (2001). Using pedagogical inquiries as a basis for learning to teach: Prospective teachers' perceptions of positive science learning experiences. *Science Education, 85*, 733–757.

White, R., & Gunstone, R. (1992). *Probing understanding*. New York: Routledge.

Yore, L. D., Hand, B., Goldman, S. R., Hildebrand, G. M., Osborne, J. F., Treagust, D. F., et al. (2004). New directions in language and science education research. *Reading Research Quarterly, 39*(3), 347–352.

Yore, L. D., & Treagust, D. F. (2006). Current realities and future possibilities: Language and science literacy—empowering research and informing instruction. *International Journal of Science Education, 28*(2–3), 291–314.

Zeichner, K. M., & Noffke, S. E. (2001). Practitioner research. In V. Richardson (Ed.), *Handbook of research on teaching* (pp. 298–330). Washington, DC: American Educational Research Association.