What Happens When Light From the Sun Shines on the Earth?

Adding Explorations of Climate Change in a Physics Course for Prospective Teachers

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Abstract

This study articulates ways we redesigned a physics course for prospective teachers to lead toward understanding the physics of climate change. We chose a narrow focus: energy transformations during the green house effect and rising sea levels. This was a self-study in which we also reflected upon ways in which we used exploring the effects of light from the Sun shining on the Earth as a context for engaging prospective teachers both in learning about science and in enhancing their view of themselves as science learners and teachers. Data sources included video of class sessions, copies of student writings and drawings, archives of postings on an electronic discussion board, the instructor’s reflections, and anonymous responses on in-class and online questionnaires. Taught entirely in the laboratory, the course emphasized questioning, predicting, exploring, and discussing what one thinks and why. The course also modeled integrating physics and literacy learning.

Each unit engaged the prospective teachers in identifying resources upon which to build, developing powerful ideas based on evidence, using those powerful ideas to develop an explanation for an intriguing physical phenomenon, developing mathematical representations for the phenomenon, and then using those mathematical representations to estimate a quantity of interest. Units included the nature of light phenomena, the nature of thermal phenomena, the influence of light and thermal phenomena on local weather and global climate change, the nature of astronomical phenomena within the Sun/Earth/Moon system, and reflection on science teaching and learning. We discuss creating a new coherent story line, designing a common unit structure modeling the nature of science, and engaging the prospective teachers in a variety of explorations and assignments, including those involving friends or family members at home.

Keywords: physics, climate change, prospective teachers, greenhouse effect, rising sea levels

What happens when light from the Sun shines on the Earth? This is the guiding question in a physics course for prospective elementary and middle school teachers. The course begins with explorations of light and shadows common in elementary schools; near the end of the course, the prospective teachers trace their evolving understandings of the physics of climate change and reflect upon their learning processes.

The nuances of talking about "climate change" or "global warming" are complex (Schuldt, 2011). We chose "climate change" because that is the language used in reports and websites such as the Intergovernmental Panel on Climate Change (www.ipcc.ch) and United States Global Change Research Program (www.globalchange.gov). In the US, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts and Core Ideas* (National Research Council, 2012) recommends a focus on "Global Climate Change" (p. 196) as one of twelve core ideas students should study in the earth and space sciences. The *Next Generation Science Standards* (NGSS Lead States, 2013) uses this framework as a guide for curricula decisions.

The purpose of the study was to document how we redesigned the course to add explorations of climate change. The study also documented how we used the context of light shining on the Earth to engage the prospective teachers in learning about science and in enhancing their view of themselves as science learners and teachers.

Reviewing Resources

Multiple resources are available online. The *American Journal of Physics*, for example, has published two resource letters on global warming (Firor,1994; Mastrandrea & Schneider, 2008). The latest cites journal articles, books, and websites for "the greenhouse effect and radiative forcing, detection and attribution of human-induced climate change, carbon cycle feedbacks, paleoclimate, climate models and modeling uncertainties, projections of future climate change and climate impacts, and mitigation and adaptation policy options" (p. 608). The US National Science Foundation established the Climate Change Education Partnership (CCEP) to encourage development of resources related to the science of climate change and its impacts (http://nsf.gov/news/news_summ.jsp?cntn_id=117685&org=NSF&from=news). The American Association for the Advancement of Science (2010) offers guidelines for teaching about climate change, including maps of learning progressions for weather, climate, and energy resources.

The US National Science Teachers Association's website (http://www.nsta.org/climate/) lists books, surveys, journal articles, interactive content models, online learning experiences, and webinars to help teachers teach about climate change issues. This NSTA website also provides links to many organizations offering resources for teachers, families, and community members. The Climate Literacy and Energy Awareness Network (CLEAN), for example, was launched in 2010 as a National Science Digital Library (NSDL) project (http://cleanet.org/index.html). The website presents principles, concepts, and activities for teaching about climate and energy.

Golden, Grooms, Sampson, and Oliveri (2010) used global climate change as a context for helping high school students learn how to use evidence in constructing arguments. Matkins and Bell (2007) taught prospective elementary teachers about the nature of science by examining global climate change issues in a science teaching methods course. Hestness, McGinnis, Riedinger, and Marbach-Ad (2011) engaged prospective elementary teachers in considering local and global implications of climate change, also in an elementary science teaching methods course. We too wanted to address those aspects of learning about climate change. Our primary focus, however, is on the science. What, we wondered, is the physics involved?

Deciding on Which Aspects of Climate Change to Focus

"Energy" is a familiar word that people use colloquially in many different ways. "Energy" also is a special word with very specific meanings in a wide variety of science contexts. The US *Next Generation Science Standards* (NGSS Lead States, 2013) identifies the definition of energy, as well as energy conservation and transfer, as disciplinary core ideas that all teachers, elementary, middle, and high school, should address. We decided to focus on the concept of energy transfer from the Sun to the Earth, to trace transformations of that energy in what is known as the greenhouse effect, and to consider the role of those energy transformations in rising sea levels. Ways that the Earth's systems interact also seemed an appropriate topic.

We decided to focus on the greenhouse effect because this term frequently appears in news about climate change and some of the physics involved seemed accessible. Articles and websites often represent the greenhouse effect in diagrams with light rays from the sun shining down on the earth, being reflected or absorbed, with some transformed into infrared radiation, re-emitted, and repeatedly reflected and absorbed, with their energy staying on Earth rather than being radiated back to space. Such greenhouse effect diagrams represent a 'story' that we thought the prospective teachers could learn to trace, based on their experiences in learning to trace ray diagrams for pinhole phenomena, already a central feature early in the course. We chose to focus on rising sea levels because the primary physical causes, additional water from melting ice on land and thermal expansion of the oceans seemed easily modeled and understood. Also they build on explorations of thermal phenomena already in the course. Extending systems thinking to this context would fit well with an initial topic in the course, considering relations among the Sun, Earth, and Moon in explaining the phases of the moon and the Earth's seasons.

Learning about weather has been a staple of school curricula, along with distinguishing local weather at a particular moment from the concept of the climate typical for a specific geographical area over a broader time period. We decided to add a unit on the influence of light and thermal phenomena on local weather to precede the new unit on global climate change.

Addition of two new units in the already crowded physics course prompted us to consider or reconsider the following questions: What are our goals? What curricular materials should we use or create? How would these new topics fit into a coherent story line making connections across topics throughout the course? How should we structure a unit? What topics, activities, and assignments should we keep? What cut? What activities and assignments should we include in the new units on weather and climate change? How should we end the course?

Studying One's Own Teaching Practices and Students' Learning

This is a self-study (Loughran, 2007) in which we reflect upon the process of redesigning the physics course as well as describe its current form. Also known as the scholarship of teaching and learning (Shulman, 2004) (http://www.carnegiefoundation.org/scholarship-teaching-learning), this type of study involves systematically collecting and interpreting data to better understand one's own teaching practices and students' learning. The driving question for the study was "How can we redesign the course to teach the physics of climate change while enhancing the prospective teachers' view of themselves as science learners and teachers?

Describing the Setting

The physics course meets in a laboratory for 2.5 hours twice a week for ten weeks. The emphasis is on questioning, predicting, exploring, and discussing what one thinks and why. The course also models integrating physics and literacy learning (van Zee, Jansen, Winograd, Crowl & Devitt, 2013a,b). By integrating physics and literacy learning, we mean learning to speak clearly, listen closely, write coherently, read with comprehension, and create and critique media resources in physical science contexts. With the new focus on developing understandings about the physics of climate change, we also have begun seeking ways to connect each unit with a global perspective, including social justice issues. We provide details on a course wiki at http://physics.oregonstate.edu/coursewikis/ph111 .

Including Faculty as well as Students as Participants

Participants were primarily female freshman and sophomore early childhood and human development majors (n = 15, Spring 2012; n = 8, Fall 2012; n = 16, Spring 2013; n = 15, Fall 2013). They elected to enroll in the physics course as satisfying one of three Baccalaureate Core science courses required for graduation. We also offered a version of this course during a summer institute for inservice elementary and middle school teachers (n = 14, Summer 2011).

Participants also included the first author as the instructor, the second author as chair of the physics department and co-instructor of the inservice version of the course, and the third author, a professor of literacy who coached us on ways to integrate science and literacy as part of an earlier project supported by the National Science Foundation (No. 0633752-DUE).

Collecting Data

Using a form approved by our Institution Review Board (IRE), we requested consent from students to collect a variety of information documenting their learning. Data sources included video of class sessions, copies of student work, postings on an electronic discussion forum, instructor’s reflections, and anonymous in-class and on-line questionnaires.

Interpreting Data

We developed a narrative interpretation (van Zee, Manogue, Roundy, Gire, Kustusch & Auparay, 2013) by reflecting upon our design process and selecting examples that illustrate student thinking during activities and assignments. The examples represent successful responses, illustrating our aspirations for student learning. We have not yet succeeded in nurturing learning at this level for all students, however; a later paper will focus on interpreting the full range of responses for selected topics. To indicate perceptions of all the students about several aspects of science learning and teaching, we refer to mean ratings on a scale of 1 (not useful) to 5 (useful) for topics and activities as well as the results of paired t-tests ($p < 0.05$) for ratings indicating changes in students’ perceptions.

Designing and Redesigning a Physics Course for Prospective Teachers

As discussed below, we contemplated several goals in designing and redesigning this physics course, drew on a variety of resources in selecting and creating curricular materials, and endeavored to create a coherent story line throughout the course while adding new topics.

Contemplating Goals

In initially proposing a new physics course, we had a pragmatic goal to gain institutional approval for the course. Our primary goal was to design a physics course that engages prospective elementary and middle school teachers in learning science in ways they will be expected to teach science as described in science education reform documents. We also wanted to address affective issues associated with the typically poorly-prepared population of students likely to enroll. In addition, we wanted both faculty and students to be able to monitor progress on an on-going basis.

Gaining institutional approval. In designing a new physics course in 2007, we started with a pragmatic goal, to create a physics course for prospective elementary and middle school teachers that fostered the student learning outcomes already established by our institution’s faculty committee for general education courses in the biological and physical sciences. These specified that students should be able to apply basic concepts and theories, to draw conclusions based on observations, analysis, and synthesis, and to make connections to other subject areas. To get the course approved, we needed to state explicitly how this new physics course would engage the prospective teachers in developing these abilities.

Engaging prospective teachers in learning and teaching physical science. A recommendation in the US *National Science Education Standards* (National Research Council, 1996) guided our initial development of the physics course, "Teachers of science plan an inquiry-based science program for their students" (p. 30). More recent US science education reform documents articulate disciplinary core ideas, cross-cutting concepts, and science and engineering practices that teachers should foster. These documents make explicit many practices in which we wanted to engage the prospective teachers: "asking questions and defining problems; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics and computational thinking; constructing explanations and designing solutions; engaging in argument from evidence; and obtaining, evaluating, and communicating information" (NRC, 2012, p. 3; NGSS Lead States, 2013, Appendix F, p. 1). We also wanted to include ways for the prospective teachers to teach science in doing assignments, participating in events for children on campus, and visiting a local elementary classroom.

Addressing affective aspects. We hoped to address affective aspects included within six strands of informal science learning (NRC, 2009), that learners who engage with science: "Strand 1: Experience excitement, interest, and motivation to learn about phenomena in the natural and physical world" and "Strand 6: Think about themselves as science learners and develop an identity as someone who knows about, uses, and sometimes contributes to science" (p. 43). Strands #1 and #6 seemed particularly important to foster in our students, primarily early childhood education majors, as many enter the course with negative attitudes toward science.

Monitoring progress. We wanted to monitor progress in a variety of ways, both for ourselves and for our students. In addition to grading assignments, we posed ungraded diagnostic questions to which students responded both before and after exploring topics. We also asked students to post their reflections on an electronic bulletin board so that those interested could read about their colleagues' learning experiences as well as their own. In addition, we administered and reported findings to the class on anonymous questionnaires via survey monkey as well as with printed forms filled out in class.

Selecting and Creating Curricular Materials

Rather than adopting a particular textbook in designing the initial version of the course, we drew on a variety of resources, primarily *Powerful Ideas in Physical Science* (American Association of Physics Teachers, 2001), *Physics and Everyday Thinking* (Goldberg, Robinson, & Otero, 2008), and *Physics by Inquiry* (McDermott and the Physics Education Group, 1996). With support from the National Science Foundation, we also developed materials that instructors can use with such curricula to support development of literacy learning in the context of learning science (van Zee, Jansen, Winograd, Crowl & Devitt, 2013a,b). In addition, we chose to focus upon topics that align well with curricula used in local schools. In redesigning the course to include exploring aspects of the physics of climate change, we also have drawn on university, state, national, and international websites providing relevant and well-vetted information.

Creating a Coherent Story Line

We wanted the prospective teachers to experience learning science (and later to teach science) as a coherent enterprise rather than encountering a series of disconnected topics. Therefore, we created a story line that they trace in writing "their own textbook" about each unit's explorations. We provide an outline listing headings and subheadings. They write and receive feedback on each section as part of their homework assignment each week.

We state explicitly on the first day of class the new theme for the course, "What happens when light from the Sun shines on the Earth?" The first unit involves explorations of the nature of light phenomena. One effect of light shining on the Earth is that cars, playground slides, and people get hot so we next explore the nature of thermal phenomena. These topics have been part of the course since its inception. In this new version, we have added units on the influence of light and thermal phenomena on local weather and then on global climate change. To make room, we had to squeeze explaining the phases of the moon and the Earth's seasons into a shorter time period, but still include them near the end of the course. In reporting upon their explorations during these units, the prospective teachers also write a reflection upon changes in their personal views about science and about science learning and teaching.

Designing a Common Structure for all Units

All of our units follow the same structure, which we designed to foster increasing scientific and mathematical sophistication in students with little background in science and high anxiety in mathematics. We discuss below the rationale for this structure with examples drawn from the prospective teachers' writings for the first unit on the nature of light phenomena. The structure of each unit models the nature of science and includes identifying conceptual resources on which to build, developing powerful ideas based on evidence, and using these powerful ideas to develop an explanation of an intriguing phenomenon. After the prospective teachers gain some conceptual understanding and comfort with the topic, we develop mathematical representations of the phenomenon and use the mathematical representations to estimate a quantity of interest.

Identifying Conceptual Resources

We begin each topic by identifying conceptual resources (Hammer, 2000; Smith, diSessa, & Roschelle, 1993) on which to build. We do this to help the prospective teachers access relevant experiences, generate initial understandings, and document their evolving knowledge.

On the first day of class, for example, we invite the small groups to think about something they have enjoyed learning about light at some point in their lives inside or outside of school, to draw pictures representing themselves gaining this knowledge, and to identify aspects of those experiences that had fostered their learning (van Zee & Roberts, 2001). A prospective teacher wrote, for example, "One experience that most of us had and that most of our students will have is drawing a sun with straight rays coming out of it." We view such pictures (see Figure 1), seen even in preschoolers' art, as conceptual resources for making and discussing ray diagrams that represent light leaving a source in all directions and traveling in straight lines.

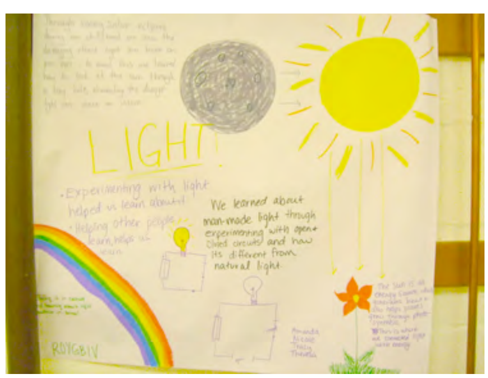


Figure 1. Small group drawings of initial knowledge about light.

Members of each small group present their drawings and positive science learning experiences to the class. Then the whole group develops a list of aspects that had fostered their learning. This first step in articulating a philosophy of learning and teaching science typically matches well with aspects of reform-based pedagogy. The list developed by the Spring 2012 class, for example, included “learning outside; making observations/ exploring; family learning; playing around; going on field trips; doing it oneself - hands-on; welcoming personal curiosity.” Creating this list and writing reflections about their positive experiences can help the prospective teachers begin to feel successful in speaking, listening, and writing in physical science contexts.

During this first session of the course, we also administer ungraded diagnostic questions to document initial ideas. One, for example, involves looking at a basketball illuminated by a single lamp in the darkened classroom. The prompt is “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.” The prospective teachers also respond to diagnostic questions about their initial understandings about the sun and the moon as well as about the nature of scientific explanations and inquiry approaches to learning and teaching. We repeat these diagnostic questions near the end of the course. (See example in Figure 2.) The prospective teachers compare their initial and current responses as part of reflecting on what they have learned during the course. For example, usually about a third initially explain the phases of the moon as due to a shadow cast by the Earth on the moon; later they recognize that the moon’s phases involve the moon’s own shadow that, like the shadow they saw on the basketball, forms on the side facing away from the light source, in this case, the Sun.

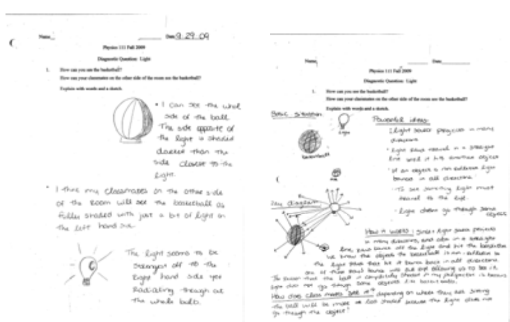


Figure 2. Prospective teacher’s initial and final responses to a diagnostic question about light and shadows.

Developing Powerful Ideas Based on Evidence

Our planned series of activities and discussions have intended end points, the powerful ideas that are the focus for the unit. We typically follow the conceptual sequence for a topic in one of the curricula noted above, although often in a more open-ended way. In addition to whole group conversations prompted by demonstrations, the small groups of prospective teachers begin developing physics principles by exploring questions they propose themselves. Sometimes we find their questions surprising, quite different from our intended curriculum; sometimes their explorations lead directly toward the topics on which we plan to focus. In either case, we are modeling a process we hope they will adopt in their own classrooms by giving students opportunities to generate their own questions and to design explorations within a particular context with materials and informal guidance provided by the teacher.

To make intuitive ideas about light explicit, for example, we work through a series of light and shadow explorations drawn from the American Association of Physics Teachers' *Powerful Ideas in Physical Science* light curriculum (AAPT, 2001; Ukens, Hein, Johnson, & Layman, 2004). After a whole group conversation predicting and then discussing how a clear vertical bulb lights a screen, we invite each small group of prospective teachers "to see what you can find out about shadows" with a lamp, barrier and screen in the darkened room. Each small group reports to the whole group, demonstrating that they can pose interesting questions and contribute useful results without preset questions and detailed directions. These experiences and discussions provide evidence for two powerful, yet readily understood, ideas: a) light leaves a source in all directions and b) light can be represented by rays traveling in straight lines.

For the first assignment, we give each prospective teacher a cardboard to use in engaging a friend or family member in playing with light and shadows, similar to our explorations in class. They post a reflection about this first experience in teaching physics on an electronic bulletin board. For example, a prospective teacher contributed the following reflection:

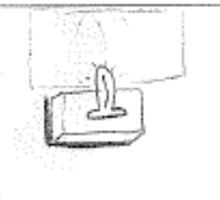
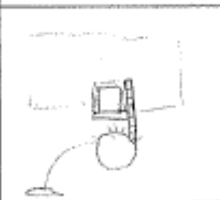
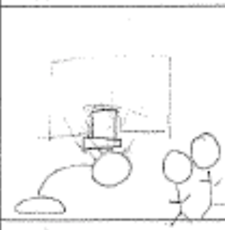
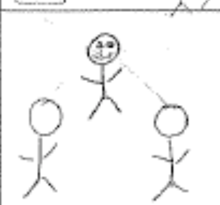
> This afternoon, I asked my two roommates in my sorority to do a little science experiment. I set up a lamp in front of the white wall in our room, closed the blinds, and turned off the lights. The two of them sat on the ground and at first, were wondering why in the world they were doing it. I told them to move the lamp up and down, forwards and backwards, tilt the card, and manipulate the various positions. Before we knew it, they had been playing around with it for about twenty minutes. They both noticed the shadow on the wall and the back of the object. They took a few pictures on their phones of the various shadows and interesting things they discovered…Watching them do this experiment rather than just doing it myself gave me assurance that this really is something that my future students will enjoy doing! The two of them had never spent that much time playing around with shadows before. They then decided to rip the cardboard back off of a notebook and cut shapes in to it to see what those shadows would look like…At first, when this was assigned I was not sure I would be able to find anyone who would be willing to try it out, but to my dismay (sic), my two roomies loved it and volunteered to help me with my next experiment as well!
>
> Fall 2013 prospective teacher's Blackboard reflection (WE)

Such friends and family assignments (Crowl, 2010; Crowl, Devitt, Jansen, van Zee & Winograd, 2013) provide immediate experience teaching science in a non-threatening environment. By working with friends and/or family members, the prospective teachers can deepen their own understandings while beginning to listen closely to someone else's thinking and responding in ways that foster science learning.

For the second homework assignment, the prospective teachers create charts that summarize their first week's exploration of light and shadows, including a sketch of the set up for each demonstration or exploration, the evidence observed, the powerful idea developed, and relevant vocabulary (see Figure 3). The chart and accompanying text provide the first draft for their own "textbook" for the course. Subsequent assignments include resubmitting the chart and accompanying text, revised according to the feedback provided.

Table 1

Evidence for Powerful Ideas about Light Phenomena

Day	Sketch of set up for demonstration or exploration	Evidence	Powerful Idea	Relevant Vocabulary
1		The light lit up all of the areas of the board	Light leaves a source in all directions	Filament: the inside of the bulb that emits light
1		The shadow from the barrier on the screen and the backside of the barrier	There are two kinds of shadows: objects block light from shining on surfaces behind the object; objects block light from shining on the back of the object itself	Barrier: item that casts a shadow Screen: white backdrop Shadow: absence of light
2		The ruler's shadow is directly next to the shadow of the barrier	Light can be envisioned as rays travelling in straight lines	Ray: line that spreads out from a central point Straight: no curve or bend
2		The light faced the object and bounced off to light our faces	To see something, light must travel from object to eye	Reflect: bounce off/ back
2		Different rays of light affect the way we see nose	Light bounces off rough surfaces, such as a nose, in many different directions	Rough: uneven surface

2

Figure 3: Prospective teacher's chart summarizing explorations during day 1.

Using Powerful Ideas to Develop an Explanation of an Intriguing Phenomenon

For each unit, we next engage the prospective teachers in exploring an intriguing phenomenon that they can explain by using the powerful ideas just developed. We want them to understand and value the development of scientific arguments by using powerful ideas based on evidence. We encourage the structure of argumentation practices presented in *Physics and Everyday Thinking* (Goldberg, Robinson, & Otero, 2008) of articulating relevant physics principles and then applying these to a particular situation. We also emphasize the importance of using visual representations to support explanations expressed clearly and precisely. Assigned readings in National Science Teacher Association journals (Iwasyk, 1999; Ross, Fisher & Frey, 2009; Schiller & Joseph, 2010) help signal that the type of discourse and argumentation we are modeling, although very different from what the prospective teachers may have experienced previously, are what the science teaching community expects. Also helpful is the presence of peer instructors, graduates of the course, who can attest both to the strangeness and to the importance of learning what for most are new ways of speaking, drawing, and writing.

Introductory physics courses discuss pinhole cameras briefly in a lecture and perhaps in a related homework problem, if at all, but we devote two class sessions and multiple homework assignments to pinhole phenomena. We consider this gradual emersion necessary for establishing the intellectual spirit and norms of discourse for which we are aiming. The following examples describe our efforts to build a positive learning environment in this context.

During the second session, the prospective teachers each construct a pinhole camera out of a toilet paper tube, wax paper, and aluminum foil, and poke a pinhole in the foil (see http://www.exploratorium.edu/IFI/activities/pinholeinquiry/viewer.html). They typically respond with amazement when they aim the pinhole camera at a lamp and see an upside down light bulb on the wax paper screen. (See Figure 4.)

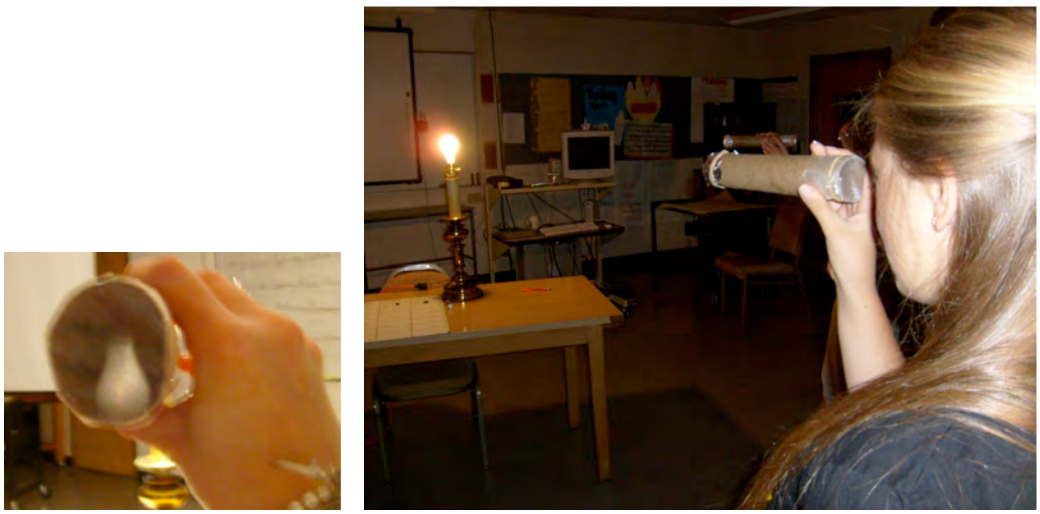


Figure 4. Seeing an upside down light bulb when looking through a pinhole camera.

By drawing sketches of possible paths for the light rays on a whiteboard, conversing with their group members, and responding to gentle guidance from their instructors, they eventually come to understand how to use the powerful ideas they just learned about light to explain this surprising phenomenon. (See Figure 5.) As the small groups prepare to present their ray diagrams and explanations to the whole group, we coach both language and actions. We encourage them to use a finger to trace the continuous path of light rays on the ray diagram.

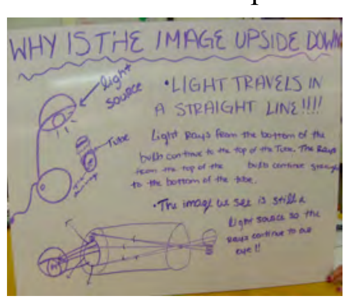


Figure 5. Small group’s large white board presentation to explain pinhole phenomenon.

In addition to the small group's ray diagram and explanation produced collaboratively on a large white board, the prospective teachers individually keep track of their learning on a notebook page. (See Figure 6.) A graduate student assistant (Devitt, 2010) designed this notebook page to mimic the format of reading strategies (pre-reading, during-reading, after-reading) that we explicitly discuss in class. On the front of the page, the prospective teachers record on the left side what they are thinking *before* undertaking an exploration - their questions, predictions, sketches of what they think will happen. On the right side of the front page, they record what they are doing and learning *during* an exploration - their observations, ways these relate to their predictions, and ideas for further exploration. They also record any new vocabulary they are using. On the back of the notebook page, they record their thinking *after* the exploration. This includes a concise statement of the powerful ideas developed and evidence on which they based these ideas. They also write a reflection summarizing this exploration. They conclude with some thoughts about "what am I still wondering?" Collecting and briefly reviewing, but not grading, these notebook pages provides an easy way for the instructor to identify issues that may need discussion.

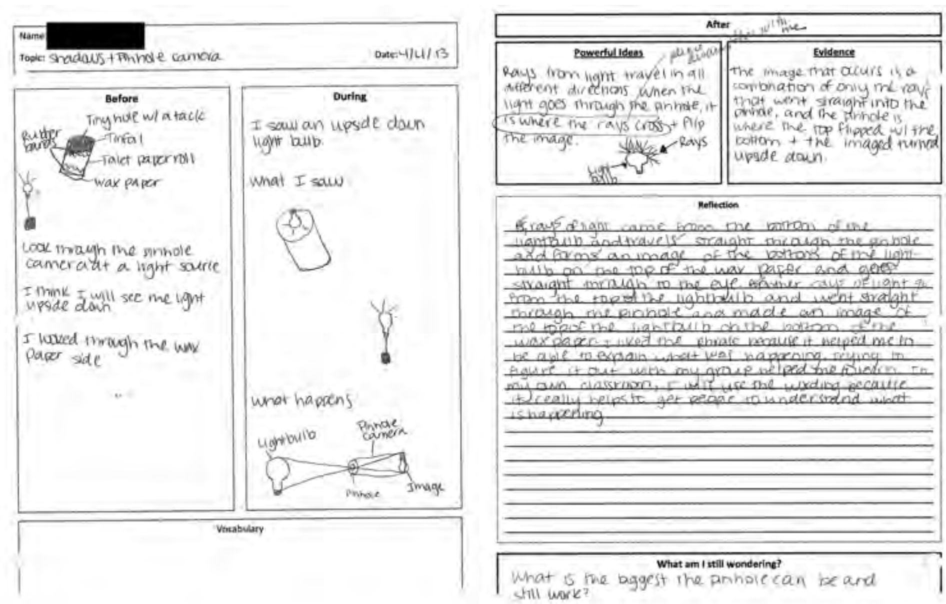


Figure 6. A prospective teacher's notebook page with her thinking about pinhole phenomena.

The process of drawing a ray diagram builds on the resource mentioned earlier, drawing a round sun with straight rays radiating from it in all directions. We note a refinement, that we can think of rays as radiating in all directions *from every point* on the light bulb, not just in one direction from a particular point as typically shown by children's drawings of the sun. We accept the term 'image' to refer to the upside down light bulb as a general term describing what cameras photograph, whether formed by a lens or by a projection through a pinhole. The word 'straight' is problematic for some as they interpret this to mean 'horizontal' and seem puzzled by its use to describe rays traveling at an angle from the top of the light bulb 'straight' through the pinhole to the bottom of the screen. We ask the prospective teachers to avoid using 'flipped' as they trace a ray through the pinhole; the pinhole does no flipping, it simply lets some light rays from the top of the light bulb pass through the hole to the bottom of the screen while the rest of the aluminum foil, in which the pinhole has been poked, blocks other rays from the top of the bulb from reaching the screen. We also ask them to use "infer" rather than "prove" in their presentations.

In explaining the projection of an upside down light bulb precisely, for example, one later wrote:

> …First, the light rays are leaving the light bulb in all directions. Some of the rays from the top of the light bulb travel straight through the pinhole to the bottom of the wax paper and display an image of the top of the light bulb on the bottom of the screen and these rays move through and leave the wax paper in all directions and some of them travel straight to our eyes…
>
> (Spring 2013 prospective teacher's own textbook, BA)

In developing explanations in the small groups, presenting to the whole group, recording thinking individually on notebook pages, writing about teaching about pinhole cameras at home, reflecting on the readings, and writing the first section of their own textbook, the prospective teachers gain experience in speaking, listening, reading, and writing in physical science contexts. Our intent is that they build confidence, as well as competence, as science learners and teachers.

Developing Mathematical Representations of the Phenomenon

After gaining some conceptual understanding of a physical phenomenon, the prospective teachers next develop mathematical ways of representing their findings. These may include geometric relationships identified in their drawings, algebraic expressions and equations justified by the physics principles just developed, and/or graphs displaying relationships among variables. Typically the small groups need gentle probing by the instructor and peer instructors to develop these representations as well as time to discuss their mathematical ideas among themselves.

During the second week of class, for example, the prospective teachers develop an algebraic equation for pinhole phenomena, based on the geometry of similar triangles, knowledge gained earlier in a mathematics course for prospective teachers. One wrote:

> The equation that represents this phenomenon is
>
> $$\frac{\text{Height of the object}}{\text{Distance from object to pinhole}} = \frac{\text{height of the image}}{\text{distance from pinhole to image}}$$
>
> There are two isosceles triangles formed. One is formed from the object to the pinhole and the other is formed from the pinhole to the image…the triangles are similar and the corresponding sides of similar triangles can be compared, so we can use the two triangles to provide proportional ratios representing the mathematics of our discovery.
>
> (Spring 2013 prospective teacher's own textbook, BA)

Using Mathematical Representations to Estimate a Quantity of Interest

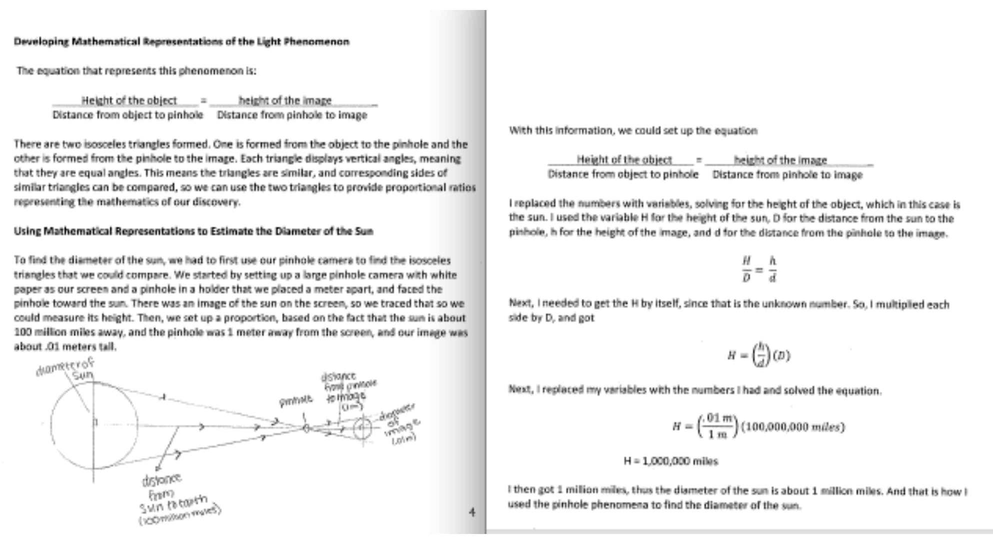
The prospective teachers then use the mathematics they have just developed to estimate a quantity of interest. We strive to have them calculate something that they will find unusual, surprising, or useful. Given our interest in the Sun as the source of the light shining on the Earth, for example, we take a field trip to the roof on the next sunny day to use the prospective teachers' new knowledge of pinhole phenomena to estimate the diameter of the Sun. (See Figure 7.) BA wrote:

> To find the diameter of the sun…we started by setting up a large pinhole camera with white paper as our screen and a pinhole in a holder that we placed one meter apart, and faced the pinhole toward the sun. There was an image of the sun on the screen, so we traced that so we could measure its height. Then we set up a proportion based on the fact that the sun is about 100 million miles away, and the pinhole was 1 meter away from the screen, and our image was about .01 meters

> tall. With this information, we could set up the equation… (shows calculation)…Thus the diameter of the sun is about 1 million miles.
> (Spring 2013 Prospective teacher's own textbook, BA)

Figure 7. The light circle on the screen is the projection of the sun formed through the pinhole.

Our intention in spending several sessions on pinhole phenomena was to gradually build the prospective teachers' expertise until they could, with confidence, draw and interpret a complex ray diagram, use ideas they understood to explain an intriguing phenomenon, use geometrical reasoning to develop and justify an algebraic equation, and use that equation to calculate something of interest. The prospective teachers wrote a detailed summary of this exploration as a homework assignment, that later became part of their own textbook. Requiring such summaries as homework as the course progresses provides opportunities for writing coherently in physical science contexts with feedback provided as needed. The prospective teachers then include revised versions in their own textbooks as shown here in Figure 8.



Developing Mathematical Representations of the Light Phenomenon

The equation that represents this phenomenon is:

$$\frac{\text{Height of the object}}{\text{Distance from object to pinhole}} = \frac{\text{height of the image}}{\text{Distance from pinhole to image}}$$

There are two isosceles triangles formed. One is formed from the object to the pinhole and the other is formed from the pinhole to the image. Each triangle displays vertical angles, meaning that they are equal angles. This means the triangles are similar, and corresponding sides of similar triangles can be compared, so we can use the two triangles to provide proportional ratios representing the mathematics of our discovery.

Using Mathematical Representations to Estimate the Diameter of the Sun

To find the diameter of the sun, we had to first use our pinhole camera to find the isosceles triangles that we could compare. We started by setting up a large pinhole camera with white paper as our screen and a pinhole in a holder that we placed a meter apart, and faced the pinhole toward the sun. There was an image of the sun on the screen, so we traced that so we could measure its height. Then, we set up a proportion, based on the fact that the sun is about 100 million miles away, and the pinhole was 1 meter away from the screen, and our image was about .01 meters tall.

4

With this information, we could set up the equation

$$\frac{\text{Height of the object}}{\text{Distance from object to pinhole}} = \frac{\text{height of the image}}{\text{Distance from pinhole to image}}$$

I replaced the numbers with variables, solving for the height of the object, which in this case is the sun. I used the variable H for the height of the sun, D for the distance from the sun to the pinhole, h for the height of the image, and d for the distance from the pinhole to the image.

$$\frac{H}{D} = \frac{h}{d}$$

Next, I needed to get the H by itself, since that is the unknown number. So, I multiplied each side by D, and got

$$H = \left(\frac{h}{d}\right)(D)$$

Next, I replaced my variables with the numbers I had and solved the equation.

$$H = \left(\frac{.01\ m}{1\ m}\right)(100{,}000{,}000\ miles)$$

H = 1,000,000 miles

I then got 1 million miles, thus the diameter of the sun is about 1 million miles. And that is how I used the pinhole phenomena to find the diameter of the sun.

Figure 8. Prospective teacher's summary of estimating the diameter of the Sun.

We continue assigning pinhole problems for several weeks in order to create a high comfort level with drawing and interpreting ray diagrams as well as with setting up and using algebraic equations in this context. Settings for the pinhole problems include our community, schools, and uses of pinhole cameras evident in historical records or global milieus. For example, the prospective teachers create pinhole problems based on objects they choose in photos shown on the Internet (e.g., http://www.pinholeday.org/) from Worldwide Pinhole Camera Day and in videos (e.g., http://www.youtube.com/watch?v=Pe8WQTgcsiE) even in another language. Pinhole camera problems also can highlight social justice issues, such as walls that governments build to keep citizens in – or others out. In 1990, for example, Ulrich Ricker and Marcus Kaiser used a pinhole camera to take photos, facing both east and west, through holes in the Berlin wall (http://www.marcus-kaiser.de/arbeiten/mauer.htm). They were celebrating that people, as well as light rays, could now move freely between East and West Germany in both directions.

Designing Connections to the Physics of Climate Change

In deciding to redesign the course to include the physics of climate change, we needed to decide what to keep or cut in the first two units on exploring the nature of light and thermal phenomena. These were tough decisions.

Deciding What to Keep or Cut in Exploring the Nature of Light Phenomena

In the original design of the course, our exploration of light phenomena also included a field trip outside to establish cardinal directions, to start a sky journal showing a stick figure with an arm pointing at the Sun (and other arm at the Moon if visible), to trace shadows on the pavement, and to predict changes by the end of class. This field trip initiated our study of the Sun and the Moon. Related assignments and activities continued throughout the term, culminating in explaining the changing phases of the Moon and reasons for seasons. We kept these topics as they connect well to the new theme of “What happens when light from the Sun shines on the Earth?” However, we omitted some challenging activities. Few people realize, for example, that when looking at a third quarter moon, one is looking at the “place” in space where everyone on Earth is about to be, as the Earth revolves around the Sun! How soon will we get “there”? We gave up acting out this configuration of the Sun/Earth/ Moon system and estimating the time for the Earth to move in its orbit through the distance from Earth to the Moon. Instead we provide a handout with a mini-lecture showing the calculation (about 3 ½ hours). We mourn this loss, as working through the mathematics builds confidence in complex three-dimensional thinking and algebraic expertise.

Early versions of the physics course also included several sessions exploring reflection in mirrors and refraction in lenses and then using both of these phenomena in explaining rainbows. We reduced these topics to one session, to develop a diagram for a ray of a particular color of light from the sun refracting as it enters a raindrop, reflecting at the inner surface, refracting again when leaving a raindrop and entering a person’s eye. This introduces a relevant concept, that white light we see from the sun is composed of a spectrum of colors, part of a larger electromagnetic spectrum. To reduce the risk of overwhelming the prospective teachers, however, we label the topic of explaining rainbows as off limits on the midterm and final.

Deciding What to Keep or Cut in Exploring the Nature of Thermal Phenomena

Our second unit, on the nature of thermal phenomena, also needed revision. We open the unit with a diagnostic question, to rank four blocks (two types of metal, wood, and Styrofoam) in order of temperature. Although feeling the blocks confirms predicted rankings of Styrofoam warmest, wood, and then the metals, the prospective teachers typically are surprised to find the measured temperature of all four blocks to be the same. This activity helps them distinguish between the concepts of heat and temperature, with their emerging understanding that the blocks are all at the same temperature, room temperature, but differ in a property of the materials, thermal conductivity, in how rapidly the blocks conduct heat energy flowing from their hands.

The prospective teachers also explore mixing hot and cold water while measuring the initial and equilibrium temperatures with digital probes and displaying the temperature versus time graphs on a computer. They note that the equilibrium temperature of a mixture would be closer to the initial temperature of the hot water if they mix more hot with cold or to the initial temperature of the cold water if they mix more cold with hot. Small groups find that the changes in temperatures ($\Delta T_{cold}/\Delta T_{hot}$) are in inverse ratio to the amounts mixed (amount of hot water/amount of cold water), but are puzzled. They expect the ratios to be in the same order (amount cold water/amount hot water) equal to ($\Delta T_{cold}/\Delta T_{hot}$), just as the ratios in pinhole cameras were and as they have been trained in math class to keep expressions of proportional relationships in a systematic order. The inverse order represented by their experimental findings is a surprise and prompts some serious sense-making about the use of evidence in science.

The hot-and-cold-water mixing explorations lead to a mathematical statement for the conservation of energy, that heat energy lost by the hot water equals the heat energy gained by the cold water (assuming the cup and air do not also gain energy from the hot water). We kept the mathematical representation of this relationship ($m_h\, c_h\, \Delta t_h = m_c\, c_c\, \Delta t_c$ with the specific heat of the hot water, c_h , set equal to the specific heat of the cold water, c_c) and related calculations as well as interpreting a graph from a latent heat demonstration with melting ice warmed to boiling. Actually, we omitted very little in this unit, just moved more quickly through the topics, with the result that the unit has ended with most of us somewhat dispirited, both students and instructors. Further refinements are clearly necessary.

Designing New Unit on the Influence of Light and Thermal Phenomena on Local Weather

We decided to bring the explorations of light and thermal phenomena together by exploring differences in how materials, such as sand and water, interact with light. We now use these observations to explain phenomena the prospective teachers likely have experienced, afternoon breezes and a cloudy sky after a sunny day at the beach.

With light sensors, the prospective teachers compare how water and sand reflect light. With equal masses of water and sand heated under the same light bulb, they find that the sand increases in temperature much quicker, at least the top layer of sand, than the water. They have learned earlier about differences in how well materials conduct thermal energy, and in how much energy is needed to change the temperature of one gram of a material by one degree Celsius (specific heat). Given values for sand and water, they use these ideas to discuss why a sandy beach is so hot on a sunny day while the water is cool, why sand not very far under the surface is so much cooler than sand on the surface, and why these differences in reflectivity, thermal conductivity, and specific heat, between sand and water, lead to the sea breezes and clouds that often occur when they are at a beach in the afternoon. After examining online a variety of diagrams representing sea breezes, they discuss the one they find most helpful with a friend or family member. Although we do not develop mathematical representations for these phenomena, we note that daily, weekly, and monthly weather predictions depend upon such mathematical models programmed into computers.

Designing New Unit on Influence of Light and Thermal Phenomena on Global Climate Change

Adding the physics of climate change to an already packed course was a daunting experience. With limited time available, we decided to focus on the greenhouse effect and rising sea levels. To illustrate this unit, we quote extensively from the prospective teachers' papers. We follow below the structure of the unit: identifying resources, developing powerful ideas, using powerful ideas to develop explanations of intriguing phenomena, and developing mathematical representations of relevant phenomena. For this unit, we added three more sections: Local, state, national and international efforts to address global climate change issues, social impact of global climate change, and educational policies.

Identifying Resources

One of the prospective teachers wrote the following about identifying resources:

> Most children grow up to learn that the sun makes things warm and clouds and rain can make the day seem cool. Understanding simple weather phenomena can help contribute to students' understanding of global climate change. Children draw lines coming from the sun from a young age, so the idea of light traveling is a familiar concept to them whether they realize it or not. There is also the concept of getting into a car on a cold (sunny) day. The car can trap heat, making the car stay warm even when it is cold outside.
>
> (Fall 2013 prospective teacher's own textbook, NE)

Other resources mentioned included noticing lower water levels in nearby lakes, less rain, earlier spring flowers, and news reports of record-breaking temperatures.

Developing Powerful Ideas

In contrast to the earlier units, we used Internet resources rather than experiments to introduce three relevant powerful ideas. We viewed and discussed in class two websites presenting the electromagnetic spectrum and a video about infrared radiation. Thus this unit took on a more familiar format, learning from information provided rather than from explorations. In the outline for writing their own textbook, we supplied the powerful ideas, shown as bolded subheadings below. One of the prospective teachers reported learning about these ideas as follows:

> **Visible light can be represented as a wave and is part of a broad spectrum of such waves.** Light is a form of electromagnetic energy. This energy travels in waves, some of which we can see, but most of which we cannot. The electromagnetic spectrum contains very large radio waves to very small gamma rays. Somewhere in between these two types of waves on the electromagnetic spectrum are light waves, which are the ones we can see. At http://missionscience.nasa.gov/ems/01_html there is a fantastic description of electromagnetic energy and how it travels. For more information about light, color and the spectrum visit: http://science-edu.larc.nasa.gov/EDDOCS/Wavelengths_for_Colors.html
>
> **Hot objects emit energy as infrared radiation.** Dr. Michele Thaller presents an interesting video about how we can observe infrared radiation, even though we can only see (with our naked eye) light waves. Dr. Thaller shows us that an infrared camera picks up infrared waves instead of light waves. These waves on the camera show as warmer colors the hotter the object and cooler colors the cooler the object. In the video, the ice cream looks purple and black but Dr. Thaller looked yellow and orange. This video can be found at http://www.youtube.com/watch?v=2--0q0XlQJ0
>
> **Materials differ in whether visible light and infrared radiation can pass through the material or are blocked.** We can see in the video that we could see the infrared radiation passing through material like smoke or fabric (as seen through the infrared camera). However, when Dr. Thaller held up the glass pane in front of her face we could not see her face through the glass (as seen

> through the infrared camera). From this we can see that visible light waves can pass through glass while infrared waves cannot.
>
> (Fall 2013 prospective teacher's own textbook, EJ)

One of the prospective teachers showed us that her computer had "thermal camera" capabilities with free software known as "photo booth". We could see ourselves and our local environment in infrared! This opens possibilities for future explorations "hands on" as well as using the Internet.

For the fourth powerful idea, we conducted a brief experiment in class. The prospective teachers held the bulbs of traditional liquid thermometers in their hands. EJ wrote, for example:

> **Liquids expand when heated.** We recorded the top of the red alcohol in the thermometer was at the 22 degree line when it had been sitting at room temperature. When we held the bulb in our hands for a few minutes, we observed that the line had risen to 28 degrees. Since we know that our body temperature is warmer than room temperature, we concluded that liquid expands when it is heated. At http://www.youtube.com/watch?v=N49wTL8NK0g , we can observe that the same phenomenon occurs with water.
>
> (Fall 2013 prospective teacher's own textbook, EJ)

These four ideas formed the basis for explaining the greenhouse effect and rising sea levels.

Using Powerful Ideas to Develop Explanations of Intriguing Phenomena

In class, we discussed diagrams of the greenhouse effect on websites such as http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-1-3.html . We emphasized tracing the rays shown on such diagrams to tell the 'story' of what was happening, in ways similar to ways the prospective teachers had learned to trace light rays to tell the 'story' of what was happening in a pinhole camera. They also had an assignment to critique several climate change websites, view their choice of the best greenhouse effect diagram with a friend or family member, and discuss what this person already knew about the greenhouse effect, help the person learn more, and reflect upon the learning process. One traced the 'story' of the greenhouse effect in writing:

> **Greenhouse effect.** The greenhouse effect is the trapping of heat using gases such as carbon dioxide in the earth's atmosphere. This heats the earth. Some of the light from the sun is absorbed by water and the surface of the earth. The rest of the light is reflected back into space. The earth heats up and releases infrared radiation. Some of this radiation cannot pass through carbon dioxide in the atmosphere and is absorbed, reemitted, and travels back to earth. This can be linked to the powerful ideas that hot objects emit infrared radiation and materials differ in whether visible light and infrared radiation can pass through the material or are blocked. The earth heats up, emits the radiation, which can then be absorbed by the carbon dioxide and reemitted directed either out toward space or back to earth...When I asked (my friend) how much he knew about the greenhouse effect, he admitted that he knew very little like myself. He or I had never had much education on the subject of the greenhouse effect or gases in high school or college up until this point. I explained to him what we had gone over in class in regards to global climate change and the greenhouse effect and the underlying powerful ideas that applied to both of those subjects. I used example how even if it's cold out that your car will be warm on a sunny day. Using terms like "infrared" and "reflection" seemed to help. We had gone over some of the websites provided in Homework 7 and learned more. …I found this website very helpful: http://epa.gov/climatestudents/basics/today/greenhouse-effect.html

(Fall 2013 prospective teacher's own textbook, HA)

On a questionnaire, we asked about the prospective teachers' initial awareness of the greenhouse effect. Responses in the Fall 2013 class (n = 15) ranged from 1 (have not heard of it) to 5 (studied in a course), with the median at 3 (have talked about it). Three mentioned studying the greenhouse effect in introductory biology, geology, sociology, and anthropology courses. One later noted "I never really understood HOW the greenhouse effect worked until (this course)."

To explore the effect of climate change on rising sea levels, the small groups had conducted a simple experiment with a highly visible and memorable effect with melting ice. One of the prospective teachers described this process as follows:

> **Rising sea level due to melting ice on land.** In class, we experimented with melting ice by taking two trays and putting a rock with ice on top of it in one tray and just ice in the other tray; the amounts of ice were equal. We then filled the trays to the brim with water. As the ice melted the tray with the ice on top of the rock began to overflow with the additional water. The water level in the tray with the ice and water mixed together did not overflow. Despite the trays having equal amounts of ice, I think the tray with the rock overflowed because all of the water from the ice was added to the level. Whereas, the tray without the rock had the ice floating in the water when we filled it to the brim so the ice was already taking up some space. National Geographic's website reinforced my theory in an article discussing sea levels. The article mentioned that if the ice sheet covering Greenland were to completely melt the rise in sea levels could claim both London and Los Angeles. See http://ocean.nationalgeographic.com/ocean/critical-issues-sea-level-rise

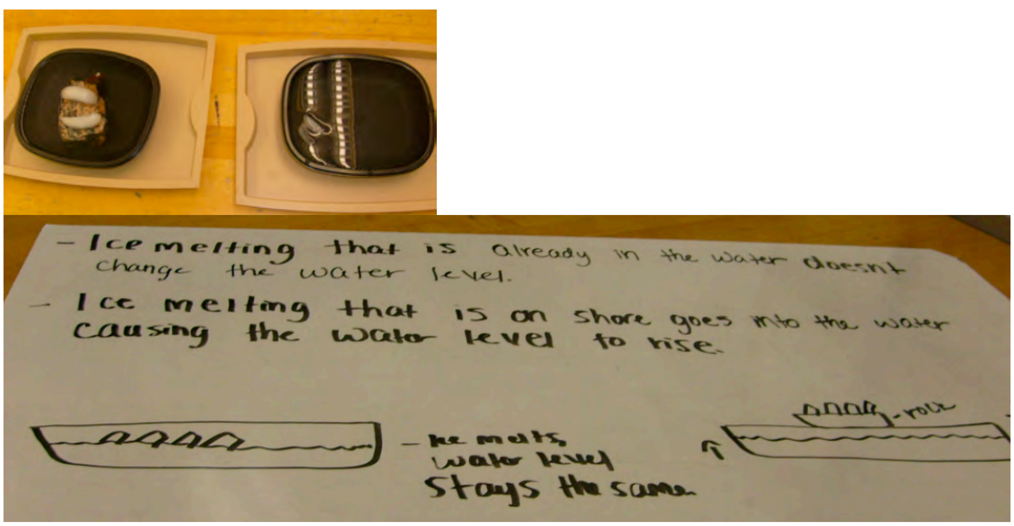


Figure 11. Comparing the effects of melting ice on rock and in water

She continued with a description of the effect of increased temperatures on oceans:

> **Rising sea level due to the thermal expansion of oceans.** When holding a thermometer in your hand you can see how just the heat from your hand causes the liquid in the thermometer to expand. The oceans are getting warmer as the earth gets warmer and this is a problem, because as we know, water expands when heated. The EPA's guide to climate change explains that while a few

> degrees may not seem like much, but the whole ocean is expanding is a big difference. http://www.epa.gov/climatestudents/expeditions/sea-level/index.html
>
> (Fall 2013 prospective teacher's own textbook)(CN)

One effect of adding the physics of climate change to the course has been new understandings we have gained ourselves; this was a surprise to the lead instructor, that about half of the observed increase in sea level can be attributed to the thermal expansion of the oceans.

Using Mathematical Representations of Relevant Phenomena

Instead of developing mathematical representations from these explorations, we used a computer program available on the Internet that predicts flooding for different levels of sea surges. The prospective teacher quoted above continued her report:

> Scientists are working on computer programs that will predict what will happen if sea levels rise. There has been a lot of research into what parts of the world will be under water if the sea levels rise. For example, in class we explored a computer program that allowed us to see what would happen to specific places in the chance of rising water levels. (http://sealevel.climatecentral.org/maps/)
>
> (Fall 2013 prospective teacher's own textbook, CN)

This unit has been a beginning, a way to at least raise awareness of the topic of climate change/global warming in this physics course. This unit also offers these prospective teachers an experience that they can understand themselves; a first step on a journey that they can now envision, based on their experiences with light and thermal phenomena, that one can develop detailed explanations and complex mathematical models to try to calculate quantities of interest. We want them to understand the enterprise in which scientists are engaged in building computer models to estimate quantities such as how much sea levels might rise in the next 100 years. The effects of storm surges and coastal flooding have been prominent in the news so websites such as http://www.noaawatch.gov/themes/coastal_inundation.php#forecasting are particularly relevant.

Examining Local, State, National, and International Efforts to Address Global Climate Change Issues

A homework assignment, incorporated in the prospective teachers' own textbooks, includes exploring relevant Internet resources such as websites sponsored by university, state, nation, and international agencies. These are open-ended assignments in which the prospective teachers are to report something they find that interests them. One prospective teacher related one of our university's studies to fishing with her family:

> **Oregon State University efforts.** (http://occri.net/climate-science/potential-impacts-of-climate-change/fish-and-wildlife). I found this article interesting because fishing is something I do often with my family. This change in the climate and the water temperatures heating up can cause diseases for fish and then they die because for fish to survive the water temperature needs to be below 17 degrees Celsius.
>
> (Fall 2013 prospective teacher's own textbook, LL)

Many of the prospective teachers reported efforts to address climate change. One wrote:

> **Oregon government efforts. (**http://www.keeporegoncool.org) The state of Oregon is also attempting to overcome the various issues that face the earth in regards to global warming. They are attempting to both raise awareness and implement plans that can help reduce the production of additional greenhouse gases in Oregon. Establishing the Oregon commission on global warming is one area where the state is trying to help reduce this issue.

(Fall 2013 prospective teacher's own textbook, SK)

Awareness of the need for climate change education also was evident. One wrote:

> **National efforts.** One aspect of national efforts to combat global climate change that I found interesting was the education aspect of the problem. One of the main goals of the national government is to prepare the country for global change. This preparation comes from educating the public about the causes and consequences of global climate change so people are aware of their role in the issue. For information visit: http://www.globalchange.gov/
>
> (Fall 2013 prospective teacher's own textbook, EK)

We explored the International Panel on Climate Change (IPCC) website in class, noting that the draft of the 2013 "Summary for Policymakers about the Physical Science Basis" had just been posted (http://www.ipcc.ch/report/ar5/wg1/#.Utxr83mtu2w). One of the prospective teachers studied the maps shown and posed a question:

> **International efforts.** In Summary for Policymakers, B.1(b) Atmosphere at the bottom of page 4 was a map of the world, which I found the image of observed changes in surface temperature 1901-2012 of interest, based off which regions seem to have the most temperature change. Why are some surface level temperatures higher than others, does it depend on the region and their industries?
>
> (Fall 2013 prospective teacher's own textbook, DK)

Reflections on these websites raised many questions and issues that could form the basis of many class sessions had we time to pursue them.

Considering the Social Impacts of Climate Change

The prospective teachers also explored websites reporting on the social effects of climate change such as the impact on rising sea levels for island nations and coastal communities. For example, one wrote:

> One part of global climate change that is not typically discussed is the social impacts of these changes to the world. Every change that occurs influences someone's life in some way. For example, low elevation countries such as those islands off the coasts of Bangladesh and India are threatened by rising sea levels. Many countries are losing parts of their land because the water levels are rising and the country ends up under water. Because of this, people are being displaced and have to find new homes. Therefore, their entire lives are impacted. For more information about this situation in the Bay of Bengal refer to this website: http://www.guardian.co.uk/global-development/2013/jan/29/sea-change-bay-bengal-vanishing-islands ,
>
> (Fall 2013 prospective teacher's own textbook, EK)

Another prospective teacher wrote about the same website:

> I read about the struggles that people on the other side of the world are facing due to the rising sea levels. They used to live on other islands and have had to move. Their homes have disappeared under the sea. It is evidence that the sea levels are rising. Here in this hemisphere we have not lost our homes yet. Perhaps this is why we are slow to change our ways.
>
> (Fall 2013 prospective teacher's own textbook, DD)

We consider discussion of such issues important, both for encouraging the systems thinking evident in the second sentence of the first quote (Every change that occurs influences someone's life…) and the realization that the second quote shows of the need for action even when changes are occurring beyond one's own environment.

Considering Educational Policies

We asked the prospective teachers to close this section of their own textbooks by reflecting upon their own prior experiences in learning about global climate change. We also asked them to visit the website for the *Next Generation Science Standards* (http://www.nextgenscience.org) and discuss these recommendations for teaching about weather and global climate change. One of the prospective teachers wrote a poignant reflection:

> Within my educational years, I have never really learned much about the greenhouse effect. Whenever the topic would come up within my high school, the teachers would just say something along the line of it's not good for our world and need to have change. That was it, now as I sit in my physics class and am reading articles about what is happening in our world, it makes me concerned for our future and even more for our children's future. I believe the educational system should talk more about it and get the younger generations involved because by the time they reach college they may not be able to really do anything to help, it may be too late.
> http://www.nextgenscience.org/next-generation-science-standards
> On page 3, within ESS2.C they talk about water and how it helps or changes our world, how our world relies on water. It slowly progresses through the different school years...The part I don't get is we never learned any of this when I was in school…now I feel like I am behind and could have been doing something to help.
>
> (Fall 2013 prospective teacher's own textbook FC)

Several activities and assessments closed this unit. We provided an array of children's trade books about climate change, for example, and invited each pair of prospective teachers to select one, peruse it together, and present a two-minute book talk in which they highlighted some aspect to encourage children to want to read the book. In the section in which the prospective teachers reflected upon their learning in the course, we asked them to write about ways that they would engage their own students in the eight practices recommended in the *Next Generation Science Standards* while learning about climate change. On the final, we asked them to draw and explain a diagram of the greenhouse effect, to discuss how the greenhouse effect may be changing the Earth's climate now and in the future, and how those changes may affect land surfaces, oceans, and people.

Redesigning the End of the Physics Course

The culminating topics of the initial version of the course were explaining the changing phases of the moon and the reasons for seasons, based upon on-going observations and conversations about the sun and the moon throughout the term. Our observational approach drew on the astronomical section of *Physics by Inquiry* (McDermott and the Physics Education Group, 1996). We were reluctant to give this up for many reasons. Watching the moon with children can occur anywhere in the world our graduates might choose to teach, requires no fancy equipment, and can build a strong connection between school and home. Just seeing the moon years later and feeling the pleasure of understanding what one is seeing may become a long-term reminder of the positive attitudes and ways of thinking that we are hoping to foster. So we kept this unit with some omissions as indicated earlier.

Documenting Progress

In order to monitor progress on an on-going basis, we embedded reflections on learning in class activities, assignments, examinations, and anonymous questionnaires. In the last section, for example, we asked the prospective teachers to discuss changes in their personal views about science and about science learning and teaching. The following response suggests that, for this individual, the course met our goals:

> In learning foundational physics and exploring scientific activities with children I have discovered that I am capable of teaching scientific concepts to others. I have gained confidence in my own knowledge and abilities…I have learned that science can be implemented as a tool to foster teamwork, self-confidence, literacy, and problem-solving skills. I have found that it can be combined with math, art, and reading to compliment the strengths of individual students…In the past, I was very wary of science and had very low confidence in my scientific ability. I have regained trust in scientific classrooms as a safe place. I feel more confident asking questions, doing the work, and conveying information to others in a field of study in which I do not specialize. This class has helped me reimagine how science can be taught...
>
> (Spring 2013 prospective teacher's reflection in own textbook, WK)

For insight into the prospective teachers' perceptions as a group, we analyzed ratings on an in-class questionnaire on the last day of class. I have been fortunate to collaborate with teachers who teach science in engaging ways. I think a key aspect of their effectiveness has been their genuine interest in science so one of my primary goals for Physics 111 has been to enhance the students' interest in science. According to the self-reports on the questionnaire for the Fall 2013 course, this occurred for the group, with a statistically significant shift ($p<0.05$) of 1.4 points from a mean of 2.9 to a mean to 4.3 on a scale of 1 to 5 for not interested/interested in science. A relevant comment was "Loved this course. I enjoyed science again for the first time in about 8 years."

Another comment provides some insight into the students' likely prior science learning experiences, "Science had always been a lecture based experience for me…" Thus another major goal for the course has been to broaden the students' visions of ways to teach science to include more open-ended inquiry approaches. According to the self-reports on the questionnaire, this also occurred for the group, with a statistically significant shift ($p<0.05$) of 2.0 points from a mean of 2.5 to a mean to 4.5 on a scale of 1 to 5 for not likely/likely to teach science through inquiry. A relevant comment recognizes the essence of inquiry approaches, "I love this teaching technique because it allows the kids to experiment and ask questions."

The teachers with whom I have collaborated have been experts in using science as the focus for learning, incorporating many learning objectives across the curriculum while teaching science. Another goal for the course is to model this, particularly integrating aspects of literacy such as listening closely, speaking clearly, writing coherently, reading with comprehension, and creating and critiquing media resources. According to the self-reports on the questionnaire, this occurred for the group with a statistically significant shift ($p<0.05$) of 2.0 points from a mean of 2.4 to a mean of 4.4 on a scale of 1 to 5 for not likely/likely to integrate science and literacy learning. A relevant comment notes "seeing how interactive science can be shows that there are so many more skills involved in science than I originally thought."

As anticipated, the highest rated activities were teaching children at an elementary school (mean of 4.8) and at Discovery Days on campus (4.7). Highly rated subject matter topics included learning about the phases of the moon (4.6), pinhole cameras (4.5), and the reasons for seasons (4.4). The students also rated highly applying what they had learned about light and thermal phenomena to explaining local weather at the beach (4.6) and global climate change (4.4). A relevant comment about the latter was "I think this is information everyone should know and I will definitely be teaching it to my students each year."

The students appreciated reading papers by teachers about engaging children in learning science (4.2); they also indicated writing their own textbook to be useful in spite of the time and effort required (4.2). A relevant comment was "The effort was worth the final result in learning." This comment sums up my perspective as well. Teaching Physics 111 is an intense experience but I learn a lot and am grateful that the students seem to think that they do too!

Reflecting Upon This Study

This study provides a window into our process of designing and redesigning a physics course for prospective elementary and middle school teachers. Given the frequency with which climate change/global warming stories now appear in the news, we realized that the prospective teachers likely would encounter increasing emphasis on this topic in formal standards as well as local impact. Therefore we decided to shift the on-going theme of the course from "What causes the phases of the moon?" to "What happens when light from the Sun shines on the Earth?"

This decision prompted reexamining our goals, seeking new resources, and trying to create a new coherent story line. Because we chose not to use a textbook, we decided to provide continuity simply by using the same structure for all units. This structure modeled the nature of science and included identifying conceptual resources on which to build, developing powerful ideas based on evidence, using these powerful ideas to develop an explanation of an intriguing phenomenon, developing mathematical representations of the phenomenon and using the mathematical representations to estimate a quantity of interest.

The physics of climate change seemed a daunting topic; we needed to identify aspects that would be accessible to our students, primarily early childhood and human development majors. We also wanted to build on topics already included in the course, the nature of light and thermal phenomena. We added a unit exploring the influence of light and thermal phenomena on local weather in a familiar context, experiencing sea breezes and cloudy afternoons at the beach. In a new unit on the influence of light and thermal phenomena on global climate change, we focused on only two topics: the physics underlying energy transformations during the greenhouse effect and rising sea levels.

What have we learned from this challenging process? With limited time and an already crowded course, we decided to focus on the physics related to what we were already doing. Our exploration of light phenomena emphasized tracing 'the story' of light rays shown in diagrams of pinhole cameras; we could envision our students tracing 'the story' of light rays shown in diagrams of the green house effect. Thinking about rising sea levels seemed readily related to our exploration of thermal phenomena. We recommend that those interested in adding climate change to a course narrow consideration to just a few topics, ones that students can connect to what they are already learning so that they perceive a coherent story line throughout the course.

Perusal of the multitude of resources on global climate change can be overwhelming. We recommend identifying specific university, state, national, and international websites for students to view and critique for effectiveness in their learning. We also recommend that they engage a friend or family member in viewing one of the websites. Such conversations can deepen their own understandings as well as broaden the impact of a course addressing climate change issues.

Although we have not tried the discussion process that Golden, Grooms, Sampson, and Oliveri (2010) illustrate, we too have a strong interest in building commitments and skills in constructing arguments based on evidence. Every unit includes a section on developing powerful ideas based on evidence, which the prospective teachers represent in the charts they create for their own textbooks. We recommend emphasizing this central aspect of doing science and providing some kind of visual, as well as oral, way to represent such argumentation practices.

Like Matkins and Bell (2007), we want the prospective teachers to emerge with a deep understanding of the nature of science. We recommend a common structure for units as one way to articulate explicitly a version of scientific processes: thinking about what one already knows, developing ideas based on evidence, using those ideas in constructing explanations, and seeking mathematical relationships that can help one predict and/or calculate something of interest.

The work of Hestness, McGinnis, Riedinger, and Marbach-Ad (2011) suggests ways to include local and global implications of climate change. We recommend identifying online resources providing examples of such implications and engaging students in relevant discussions.

To echo one of our students: we need to talk more about climate change and get the younger generation involved! Those of us teaching teachers may not experience the extreme events that projections of climate change forecast by the end of this century. From our perspective, however, we are responsible for engaging our students in understanding some of the science underlying these forecasts, educating them to base judgments on evidence, and encouraging them to become citizens aware and able to participate in local, national, and international efforts to address these issues.

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