

1st
Edition

Exploring Physical Phenomena

Emily van Zee and Elizabeth Gire

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What happens when light from the Sun shines on the Earth?

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Preface

Exploring Physical Phenomena: What happens when light from the Sun shines on the Earth?

This textbook is intended for use in laboratory-centered physics courses for prospective and practicing elementary and middle school teachers. By exploring physical phenomena in class, participants learn science in ways in which they are expected to teach science. The emphasis is upon questioning, predicting, exploring, observing, discussing, reading, and writing about what one thinks and why.

This textbook also is appropriate for use in general science courses that explore some of the physical phenomena underlying global climate change. In addition, organizations such as museums, youth groups, or senior citizen programs may find one or more units a feasible framework for offering extended science learning experiences to the public during workshops and/or special events. Some of the activities also could form the basis for on-going exhibits.

The text assumes that the participants will be working at tables in small groups rather than sitting in rows listening to lectures. However, the course has been adapted for remote learning. Most of the equipment involves everyday materials available in homes, schools, and offices. Regular bulb thermometers can be substituted for the digital temperature probes described in the text. Participants can use a cell phone app to measure reflectivity if they do not have light sensors. Those without access to motion detectors can use the graphs provided in the text to learn about the phenomena explored with these devices.

The level of mathematics required assumes proficiency in mathematics taught in K-8 classrooms. Also assumed is the willingness to strengthen some high school mathematics skills as needed. These include using the geometry of similar triangles, interpreting the heights and slopes of line graphs, and solving linear algebraic equations.

A. Unit Structure

Each unit follows the same structure:

- **Identifying resources** participants bring to the study of a topic from their prior experiences.
- **Developing central ideas** based on evidence from exploring physical phenomena with everyday equipment and materials.
- **Using these central ideas to explain intriguing physical phenomena.**
- **Developing mathematical representations** of the phenomena.
- **Using these mathematical representations to estimate a quantity of interest.**
- **Making connections to educational policy and the US Next Generation Science Standards (NGSS Lead States, 2013).**

By central ideas, we mean understandings about physical phenomena that students develop while making sense of their observations. These ideas emerge from the students' discussions with one another as well as with the instructor. These central ideas also are powerful ideas because they form conceptual models useful in describing and explaining the phenomena explored. The units also develop expertise in generating and interpreting multiple representations of phenomena such as sketches, geometric figures, line graphs, and algebraic equations.

The theme for the course is: *What happens when light from the Sun shines on the Earth?* The first unit focuses on the nature of light phenomena. Students explore questions such as how light travels from a source, what affects the size and shape of shadows, how pinhole cameras work, how light reflects from both smooth and rough surfaces, and what happens when light shines through materials such as water and prisms? Students develop central ideas based on evidence from exploring these phenomena and use these understandings to think about what causes rainbows.

When light from the Sun shines on the Earth, things often get hot, so the second unit explores the nature of thermal phenomena. Why, for example, do some things feel hot or cold, how is energy conserved when mixing hot and cold water, and what happens when ice melts, liquid water warms, and then boils?

The third unit considers the influence of light and thermal phenomena on the water cycle and local weather. Students develop central ideas about forms of energy transfer such as radiation, reflection, absorption, conduction, and convection. They also explore properties of materials such as thermal conductivity and specific heat. They then use

these ideas to explain weather phenomena. In particular, students develop explanations for why, after a sunny day at the beach, the sand is hot, water cool, and cloudy skies often occur along with sea breezes in the afternoon.

The fourth unit considers the influence of light and thermal phenomena on global climate (van Zee, Roberts, & Grobart, 2016). Questions include what happens to energy from the sun as it gets reflected or absorbed by the oceans, land forms, and atmosphere? What is the greenhouse effect and how does it modulate global temperatures? Students review websites presenting climate change indicators in the US, social issues, military issues, and ways to take action. They also review websites presenting local, state, national, and international efforts to understand and address concerns about changes in the global climate. As part of this unit, the students also explore motion to think about how to interpret graphical representations of changing phenomena— where something is, its position or current value; how that position or value is changing, its speed or rate of change; and how its speed is changing, its acceleration, where the ‘it’ may be a car speeding up but also could be the mass of melting glaciers all over the Earth.

The fifth unit extends throughout the course. On-going observations of the Sun and the Moon provide evidence for thinking about why day and night occur, why the Moon seems to have different shapes at different times, and why many places on the Earth experience different seasons at different times of year. Excerpts from writings by Galileo, Newton, and other scientists provide insights into the history of thoughts about the Earth’s place in the Universe. Explorations throughout the course also provide contexts for reflecting upon the nature of science as well as upon the nature of science learning and teaching.

Each unit ends by making connections to educational policy, such as recommendations articulated in the *US Next Generation Science Standards* (NGSS Lead States, 2013). In particular, students reflect upon ways in which their explorations and developing understandings exemplify the science and engineering practices, crosscutting concepts, and disciplinary core ideas presented in this document.

B. Class Sessions

This textbook can support classroom-based, hybrid, and online courses. Our course meets twice a week for 2.5 hours each session for ten weeks. The supplementary materials may be used to extend instruction for a semester. Class sessions include documenting

initial knowledge, exploring phenomena, recording progress during explorations, discussing interpretations, writing to solidify understandings, and closing by reflecting upon what learned and what one is still wondering.

1. *Identifying Student Resources*

Each unit begins with a diagnostic question to which students respond in order to document what they already know about some aspect of the phenomena they will be exploring. Some diagnostic questions require drawing and/or writing responses individually. Others involve small group conversations and brief presentations to the whole group. Responses to these diagnostic questions are not graded.

Diagnostic questions alert students to the context of upcoming explorations; they alert the instructor to prevalent ideas on which the students can build as well as to those that may need refining. Many initial ideas are reasonable within everyday circumstances rather than misconceptions that need to be corrected. The notion that a force is necessary to keep something moving, for example, is reasonable when thinking about everyday experiences in pushing objects along rough surfaces. Refining that notion involves considering the effect of different surfaces on the force needed; less force is needed to keep something moving at the same speed on smooth surfaces such as ice. If no friction with the surface and no air resistance occurs, no force is needed to keep something moving at the same speed in the same direction. Recognizing such conditions of applicability is an important aspect of learning physics. Instead of memorizing Newton's first law with a shrug as a counterintuitive abstraction impossible to believe, students can understand it as a sensible statement, that a moving object stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force.

Responding to diagnostic questions can activate *resources* from prior experiences that students can build upon in thinking about and exploring physical phenomena. The focus on reflecting upon one's own learning in this course also activates *epistemological resources*, from prior experiences that students can build upon in thinking about and exploring learning phenomena (Hammer & Elby, 2003). Students respond to some diagnostic questions again later in the course, compare their initial and current responses, and write about their learning processes with evidence drawn from their initial and current responses to support their claims. In an on-campus course, such diagnostic questions have been initially asked on handouts that students completed in class. The

instructor collected, viewed, and stored the responses until returning them after students had completed handouts documenting their current understandings near the end of the course. In the remote learning setting, the students responded in class to ungraded surveys, both initially and near the end of the course. Both responses were accessed and stored electronically.

2. *Exploring Phenomena*

The units focus on doing and interpreting explorations of phenomena in class. Most equipment can be found in everyday settings such as kitchens, playrooms, and offices. Some activities and assignments assume students have access to a computer and to the Internet both inside and outside of class. Suggestions in the text reflect our setting of a classroom with tables at which small groups work together. Online students could collaborate in small groups via their course's electronic network or in breakout rooms. It would be best for interested individuals not enrolled in a course to explore phenomena with friends and/or family members rather than alone, but access to a variety of perspectives will be possible through reading the example student findings and interpretations.

The text presents the explorations as numbered **Questions** with bulleted statements that suggest what to do. These directions are not intended, however, to be handed out in class. The expectation instead is that the instructor will pose these general questions, provide the small groups with equipment needed, and offer some initial oral suggestions that the students see what they can find out by using the equipment to explore the phenomena. This open-ended format encourages active student engagement in designing explorations and interpreting findings.

This instructional approach assumes active engagement by the instructor and assistants as well. We recommend arranging for one or more graduates of the course to serve as learning assistants (LAs) for independent study credit or for stipends if department funding is available. Physics majors interested in teaching careers also have served as LAs for us as well as graduate students as teaching assistants (TAs). The instructor and such assistants circulate among the tables, listen in to what group members are saying, observe what the students are drawing or doing, and then ask a question or offer a comment only as needed to help a group to make progress. This process proved difficult in the remote learning setting as one cannot monitor what is happening across multiple groups while

assisting one group. It is important to listen first to what is happening when joining a breakout room before intervening, or not.

A staff member may simply ask a small group “what are you doing?” to initiate a conversation that encourages students to clarify for themselves whether what they are doing and thinking makes sense in moving toward whatever is the goal. The staff member may follow up with “why are you doing that?” and/or “how is that helping you?” Such gentle guidance is essential for nudging groups along while also providing opportunities for students to design and undertake inquiries in ways that interest them. Alan Schoenfeld (1992) suggests asking these questions to help students avoid going down unproductive paths in solving mathematics problems. Such questions also can help students learn how to monitor their own progress eventually in designing, conducting, and interpreting explorations.

3. Recording Progress During Explorations

Keeping track of what one is doing and thinking is important. In our course, students use a template for a physics notebook page on which to record their notes during class. When students submit homework assignments, the instructor may ask them to submit these notebook pages as well, perhaps for a grade or just to get a sense of how students are doing. This textbook assumes students are using this physics notebook page but instructors may prefer to have other ways for students to document what they are doing and thinking in class.

The recommended physics notebook page is for students to use to keep track of what they are doing and thinking during explorations: [here](#) (docx) or [here](#) (pdf).

This physics notebook page template is shown with explanations of the various sections: [here](#) (docx) or [here](#) (pdf). Sections on the front of the physics notebook page include the *Topic* of the exploration, the students’ initial ideas and plans *Before* starting their exploration, their observations and thoughts about what they are observing *During* their exploration, and relevant *Vocabulary*.

Example: Front of Physics Notebook Page

Topic: State the focus of the exploration: what question(s) are you asking?

Before column. Before starting your exploration, think about and discuss with your group members what you know already about this topic, how you plan to conduct the exploration and what you think you might find out. Record these initial ideas in the “Before” column. Draw pictures to represent your plans and predictions.

During column. During your exploration, record what is happening, what you observe, and what you are thinking about what you are observing. Include sketches of equipment and observations. Confirm or disconfirm predictions and describe some possible next steps.

Vocabulary. Note any words that are new and their definitions.

Sections on the back page refer to what happens after collecting data and recording these findings. These sections include *Central Ideas* that emerge from interpreting findings, the *Relevant Evidence* on which you are basing those ideas, the *Rationale* that justifies how the evidence supports the claims being made with these ideas, a *Reflection* about the exploration, and *What you are Still Wondering*.

Example: Back of Physics Notebook Page

After: Central Ideas. After your exploration, record any central ideas that have emerged from your observations and discussions.

After: Relevant Evidence. Also note the evidence on which you have based these ideas.

After: Rationale. State explicitly how the evidence is relevant and supports the claims you are making in stating the central ideas. Also explain why this result is important.

After: Reflection. Then write a reflection about whatever you want to remember about this experience – perhaps how what you learned connects to other experiences, how you learned what you learned, and what implications these findings might suggest for the next exploration or for teaching this topic in your own classroom.

After: Wonderings. In addition, briefly state what you are still wondering in this context.

Our students make copies of the template of the two-sided physics notebook page, punch holes in the copies, and use a 3-ring binder in which they store the notebook pages and handouts. They bring copies of the physics notebook page to class to use during explorations. Instructors may prefer to recommend other processes for documenting explorations in this course.

Entries on the physics notebook pages in class serve as notes for writing a coherent summary of **questions, initial thoughts and plans, findings, and interpretations** as a laboratory report after class. For the most effective learning experience, students complete explorations and summaries before reading the example student findings and interpretations included in the online text.

Adam Devitt designed these physics notebook pages when he was assisting in this course. He was a special education elementary school teacher enrolled in a graduate program in science education. He based his design of these physics notebook pages by analogy with “before, during, and after” reading strategies that enhance literacy learning (Devitt, 2010; Winegrad & Devitt, 2009). The pages have been slightly modified with the addition of a *Rationale* section and revision of some of the suggestions in the template with explanations of the various sections.

4. Discussing Interpretations of Findings

Initial discussions interpreting findings occur in the small groups. It is important, however, for the whole group to come to consensus on what the observations were and what these findings mean. There should be a clear articulation of one or more central ideas that emerge from the exploration, the evidence upon which the claims are based, and the rationale that discusses how the evidence supports the claims and why this result is important. This coming to a shared understanding about what happened and what one can infer from the findings can occur through small group presentations and/or instructor facilitated whole-group discussions.

Small group presentations maximize the involvement of individual students in developing interpretations and ways to present these interpretations to the whole group. Students need to plan and rehearse how every member of the group will contribute to what they are reporting about their findings and interpretations. If the small groups have been exploring the same phenomena in different ways, suggesting a different focus to different groups will help multiple small group presentations remain interesting and informative.

As small groups are working on their presentations, the instructor and assistants visit each group briefly to look at what the students are putting on a poster (large whiteboard) and to listen to what each student is planning to say. This way the instructor and assistants can help shape what the students choose to present and address any issues that need

refining. The group members should include the process of resolving any such issues as part of their presentation.

Facilitating whole group discussions involves listening to what students say, welcoming contributions from a variety of individuals, and encouraging student/student interactions. One way to encourage student questioning is to paraphrase what someone just said and wait before saying anything more. Listening to statements puts students into a conversationally appropriate position to ask a question. If the instructor waits without responding to that question, another student may venture an answer, which may prompt yet another student to risk offering a contribution to the thinking (van Zee & Minstrell, 1997). Although time-consuming, such vigorous student/student discussions can create a meaningful context for students to make sense of their findings before leaving class.

It is important for the instructor to resist the temptation to present a quick coherent summary of what was to be learned. If this occurs frequently, students tend to wait for it and not engage as well in making their own sense of what has happened. The extent to which the instructor feels compelled to ‘tell answers’ likely will vary, however, with the time to the end of class, the importance of the current topic to later topics, the apparent engagement of the students, and everyone’s patience. We believe that the more group members can generate their own ideas, resolve puzzles themselves, and develop coherent arguments supporting their claims, the more they will learn.

Fostering small group presentations and/or whole group conversation near the close of the students’ explorations is an important step in helping to clarify and refine understandings. Such presentations and conversations also will help students develop the skills in argumentation advocated in the *US Next Generation Science Standards* (Lead States, 2013). The intent is for the students to be the ones who articulate emergent central ideas, state relevant evidence, and provide rationales to explain how that evidence supports the claims being made and why the result is important.

Similar interpretative processes occur during subsequent sessions when students use the central ideas developed previously in order to explain intriguing phenomena that they have just explored, to develop mathematical representations of the phenomena, and/or to use these mathematical representations to estimate a quantity of interest.

5. *Writing to solidify understandings*

Scheduling time near the end of class for students to write about what they have understood helps solidify understandings about the physical phenomena explored and the learning that occurred during the session. Sometimes this can be an open-ended opportunity to reflect on what seems most interesting and/or important to the students but often the instructor may choose to provide some structure such as a table to complete, a drawing to be made, or a prompt for a summary statement. Many of the optional handouts provide such structure. These efforts do not need to be collected nor graded. They are intended to be the beginnings for students to write a coherent summary prepared at home.

6. *Reflecting Upon What Learned and What Still Wondering*

At the close of class, members of each small group reflect together upon what they have just learned in class, write a brief statement of what was most interesting to them, and articulate a question that expresses what they are still wondering. They record these thoughts briefly on *exit tickets* that the small groups turn in as they leave class. In the remote learning setting, the students responded individually to ungraded surveys with the essay questions *What was most interesting about what you learned today* and *What are you still wondering*. This provided immediate feedback to the instructor, which was very helpful in becoming aware of issues that students might otherwise have not expressed.

If a member of each group reports orally to the whole group, students also hear what others have learned and are still wondering. These brief reflections often provide insights into what was puzzling and needs clarification, next steps that might not otherwise have been contemplated, and practical matters that need attention. Sometimes the students' questions get the whole class thinking about the next exploration! Although time-consuming, such oral as well as written reflections can foster a sense of community and enrich the wonderings as well as the understandings with which students leave the classroom.

This practice was inherited from Dr. John Layman, a physics professor who taught a similar physics course at the University of Maryland College Park. One of his graduates strongly recommended continuing this closing ceremony as she had found it very

meaningful. Apparently some of our graduates feel this way as well as several have reported choosing to continue this practice with their own elementary students.

The instructor can indicate sections of the online text that are relevant to the explorations undertaken during that class and/or to some of the questions just raised. Many of the students' questions will not be addressed in this course, however. It is important to acknowledge such questions as an aspect of doing science. Scientists frequently generate intriguing questions that they cannot immediately explore within their current research. Generating questions about whatever one is doing and thinking can become a helpful practice no matter in what field of endeavor one is engaged.

After class, we have posted the relevant sections of the text online. Earlier access to the text may inhibit student learning. We believe that students will learn more, as well as build confidence and competence in doing science, if they use the online text as a means for confirming understandings that they have already developed themselves through their explorations and discussions in class.

C. Assignments

As is typical in physics courses, assignments include solving a variety of word problems related to the physical phenomena explored in class. The students also report their ongoing observations of the Sun and the Moon on a weekly basis. These form the evidence later in the term for developing explanatory models of day and night, the phases of the Moon, and the Earth's seasons.

Assignments also emphasize integrating science and literacy learning, such as speaking clearly, listening closely, writing coherently, reading with comprehension, and creating and critiquing information provided through electronic media (van Zee et al., 2013a,b). As prospective teachers, our students create a children's book based on their explorations in class. They also make connections in each unit to the *US Next Generation Science Standards* (NGSS Lead States, 2013) adopted by many departments of education.

Suggested assignments also include engaging friends and family members in learning about the phenomena that students just explored in class (Crowl et al., 2013). Such assignments can enhance the students' confidence in teaching science as well as contribute to educating citizens about the nature of science as well as about the evidence underlying concerns about climate change. The students write reflections about what happened, what the learner(s) asked, said, did, and found, and what they learned about

science learning and teaching. By posting these reflections on an electronic discussion board, they can learn from one another's experiences.

The students also reflect upon their learning processes, how they are making sense out of what they are learning each week, what aspects they want to remember, and what questions they still have. These reflections also are helpful for alerting the instructor to issues that need to be addressed and for suggesting ways to connect topics in the course to the students' interests.

Readings include articles by teachers reflecting upon exploring similar phenomena with their students as well as internet resources relevant to phenomena explored in class. The suggested *before, during, and after reading strategies* (Winegard and Devitt, 2009) are shown [here](#) (docx) or [here](#) (pdf).

The students access and critique internet resources relevant to university, state, national, and international efforts to address issues related to global climate change. They also explore websites presenting climate change indicators, social issues, military issues, and ways to take action. The expectation is that students will read enough to become aware of such resources and to find something interesting to report; they are not expected to read these materials in depth.

Students submit printed homework and reading assignments in class; some instructors prefer submission through an electronic platform (Canvas). Midterm and final examinations complete these formal assessments of students' learning. Currently the midterm is a 'sit down' affair during a class session where students can use their notebooks (but not their cell phones) for up to the full 2.5 hours of class if needed. The final currently involves preparing at home a file with responses to the questions and submitting this file online. Some of the questions include comparing students' responses on the same diagnostic questions early and late in the course and discussing how they learned what they learned based on the evidence provided by these responses.

D. Equipment

This course is laboratory-centered, which means every session involves some kind of exploration. Most of the equipment involves everyday materials found in homes, schools, and offices such as toilet and paper towel rolls, aluminum foil, wax paper, cardboard, flashlights, pots, hot plates, jars, plastic containers, etc. The Instructor's Guide includes a detailed list, or you can find it [here](#). Access to the internet is assumed inside and outside

of class. Usually at least one member of a small group has a computer laptop that can be brought to class. We use three digital probes:

1. A light probe (TI light intensity probe, <https://www.vernier.com/products/sensors/tilt-bta/>, \$16 with Go-Link interface (\$69). (This is no longer in production but may still be available via a web search.) Many students, however, have cell phones that include a light meter application so a web search for current light meter apps would be helpful, particularly for remote learning courses.)
2. A temperature probe (Go!Temp, <http://www.vernier.com/products/sensors/temperature-sensors/go-temp/>, \$39).
3. A motion detector (Go!Motion, <http://www.vernier.com/products/sensors/motion-detectors/go-mot/>, \$129).

Each group uses 1 light probe, 2 temperature probes, and 1 motion detector. If necessary, the instructor can use only one motion detector with the entire class. Regular bulb and tube thermometers can be used rather than the digital temperature probes. The students can use a cell phone app for measuring reflectivity rather than a light probe. The text also includes screen shots of the relevant graphs so that students without access to digital equipment can still think about the topics addressed. They will miss, however, the wonderful learning experiences these devices can provide.

E. Connection to US *Next Generation Science Standards*

This course addresses aspects of the following disciplinary core ideas, crosscutting concepts, and science and engineering practices suggested in the *Next Generation Science Standards* (Lead States, 2013) <http://www.nextgenscience.org>:

Relevant Disciplinary Core Ideas Addressed

Physical Sciences:

PS1A:Structure and Properties of Matter

PS2A:Forces and Motion

PS3A:Definitions of Energy

PS3B:Conservation of Energy and Energy Transfer

PS4A:Wave Properties

PS4B:Electromagnetic Radiation

Earth and Space Sciences:

ESS1B: Earth and the Solar System

ESS2D: Weather and Climate

ESS3D: Global Climate Change

Crosscutting Concepts

Patterns

Cause and effect

Scale proportion and quantity

Systems and systems models

Energy and matter, flows, cycles and conservation

Structure and function

Stability and change

Science and Engineering Practices

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.

Obtaining, evaluating and communicating information.

At the close of each unit, the students write reflections about which of these dimensions of science learning they have been experiencing and how they might engage their own students in similar ways.

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this course. This open-source textbook includes work supported earlier by the National Science Foundation under Grant No. 0633752-DUE, *Integrating Physics and Literacy Learning in a Physics Course for Elementary and Middle School Teachers*. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the grantees and do not necessarily reflect the views of the National Science Foundation.

Two papers describe this effort to integrate science and literacy learning in a physics course for prospective teachers (van Zee, Jansen, Winegrad, Crowl, & Devitt (2013a, b). Another describes ways we later included global climate change issues (van Zee, Roberts, & Grobart, 2016). Professor Winegrad and Adam Devitt, a graduate assistant who was an experienced elementary special education teacher, developed a handout describing before, during, and after reading strategies for use in the course (Winegrad & Devitt, 2009). Adam also created the before, during, and after design of the Physics Notebook Page in analogy to those reading strategies. In addition, he documented literacy activities he initiated in the course (Devitt, 2010). Michele Crowl, a graduate assistant who was a former science museum educator, invented the friends and family assignments (Crowl, Devitt, Jansen, van Zee, & Winegrad, 2013). Katie Kizer, an undergraduate peer instructor, created a website documenting the course at <http://sites.science.oregonstate.edu/physics/coursewikis/ph111/doku81aa.html?id=start>.

Many of the suggested readings were written by teachers participating in NSF No. MDR-9155726, *Investigation of Questioning Processes during Conversations about Science*, Emily H. van Zee, PI, University of California–Berkeley; NSF No. 9986846, *Case Studies of Elementary Student Inquiry in Physical Science*, David Hammer, PI; Emily van Zee, co-PI, University of Maryland College Park; and a series of small grants from the Spencer Foundation under the Practitioner Research program, including *Fostering Teachers' Inquiries into Science Learning*, Emily H. van Zee, PI, University of Maryland, College Park. Participating teachers included Mary Bell (2006), Claire Bove (2007), Kathleen Hogan (2007), Christopher Horne (2007), Marletta Iwaysk (1997), Akiko Kurose (2000), Diantha Lay (2000), Jamie Mikeska (2006), Constance Nissley (2000), Jessica Phelan (2006), Deborah Roberts (1999, 2000, 2007), Patricia Roy (2006), Dorothy Simpson (1997), and Kathy Swire (2006).

With consent forms approved by the Oregon State University Institutional Review Board (IRB), we ask students for permission to video-record class sessions, to make copies of student writings and drawings, and to photograph artifacts such as large white boards that small groups create to present and discuss their findings. Students contributing their work to this open-source textbook in these and other ways include Nicole Acadio, Mackenzie Belden, Alexia Berg, Lauren Bickhaus, Rachael Brickson, Lindsay Carlton, Sierra

Christianson, Erica Chelgren, Kirsten Clark, Nina Coleman, Natalia Cox, Maddison Cruz, Bridget Eby, Colleen Ellis, Kirby Erdman, Judith Ford, Nathalie Gaebe, Emma Grobart, Jorgan Hanson, Rebecca Huber, Justine Hynes, Tylyn Jones, Mikaela Kerr, Andrea Kenagy, Camryn Kimberly, Katie Kizer, Alison Latham-Ocampo, Emily Lemons, Jordan McCarty, Hannah Nealy, Paige Noonan, Natasha Ostertag-Hill, Andie Porta, Kortney Reddick, Zhanè Richardson, Shanna Roast, Sage Robertson, Kathryn Rodriggs, Erin Ross, Kaila Smith, Maggie Stewart, Joslyn Strickler, Danielle Taylor, Nathan Tran, Sarah Van Kessel, Courteney Vogt, Trinity Whitaker, and Stacey Zaback.

We have been very fortunate to have had excellent mentors and many opportunities to participate in and/or to learn about research and curriculum development projects while teaching and learning science with preschoolers, school children, undergraduates, graduate students, teachers, and the public, inside and outside of formal settings:

The first author, Emily van Zee, would like to thank Professor Gerald Holton for introducing her to the community of physicists who care about teaching when she worked for him as a research and editorial assistant during the early years of *Project Physics* (Holton, 2003; Rutherford, Holton, & Watson, 1971). She enjoyed learning not only about ways to engage students in exploring physical phenomena but also about historical, philosophical, and cultural aspects of the development of physics principles. The importance of providing access to such broader views underlies her inclusion of aspects of these perspectives in this *Exploring Physical Phenomena* open-source textbook.

Betty Roald, a talented elementary school teacher, welcomed the first author, as a stay-at-home Mom, to teach science to wiggly first grade students. The first author remembers sitting on the floor with the children around her while engaging them in explorations suggested in a book about how bodies work (Allison, 1976). Similar volunteer experiences with young children and older scouts in both formal and informal settings prompted her later support of a graduate assistant's initiative in inventing the friends and family assignments, now a regular part of our course (Crowl et al., 2013). The first author learned about the Moon from Leslie DeWater, a talented fifth grade teacher as well as master teacher in the University of Washington's physics programs for teachers.

The first author also would like to thank Professor Arnold Arons (1972, 1977) and Professor Lillian C. McDermott (1993, 2016) for changing the way she teaches. The first author joined the Physics 101-102, 103 staff at the University of Washington when it was the setting for the development of the *Physics by Inquiry* curriculum (McDermott, 1990; McDermott and the Physics Education Group, 1996; McDermott, Rosenquist, & van Zee, 1983). Earlier, as a new middle school science teacher, the first author had taught students in the way she had been taught, by telling them what she thought they should know.

Here, however, she learned how to teach in a new way, by moving among small groups of students sitting at tables as they worked together exploring phenomena. She learned to listen closely to what the students were saying to one another, to intervene (or not) with a comment or question, and to answer a question with a question designed to help prompt the next step in thinking.

Petra Carrera, Rafael Escribano, Gabriel Florentino, Luanna Gomez, KimBerly Petitt, and Darrell Simms were particularly insightful about their learning processes as students and/or peer instructors in the Physics 101 series. The first author's experiences in teaching these courses motivated the inquiry-based pedagogical approach as well as some of the light, thermal and astronomy activities that she adapted while designing and teaching this physics course for prospective teachers. Also relevant was the emphasis on documenting and interpreting student learning, such as ways students used multiple representations, particularly those involving motion graphs (McDermott, Rosenquist, & van Zee, 1987). In addition, the first author became aware here of the extensive science curricular resources developed earlier with NSF support for use with elementary and middle school students (National Academy of Science, 1996).

With expert guidance from Professor Lee Beach (1990), the first author undertook studies of cognition and metacognition, particularly in exploring ways people use information while making decisions (van Zee, Palunchowski, & Beach, 1992). She also began studies of the ethnography of communication with Professor Gerry Philipsen (1994) about ways in which people talk thoughtfully with one another; she was particularly interested in the role of questioning during such discussions. These studies contributed to her interest in and awareness of many aspects of discourse that affect how students think and learn.

The first author enjoyed collaborating with a high school physics teacher, Jim Minstrell, in documenting and interpreting how he used questioning to guide student thinking (van Zee & Minstrell, 1997a,b). Her post-doctoral research focused upon *An Investigation of Questioning Processes during a Cognitive Approach to Physics Instruction* with support from the James S. McDonnell Foundation. We found that he asked questions to help students make their meanings clear, to consider various points of view in a neutral manner, and to monitor the discussion and their own thinking. He had developed a computer program, *Diagnoser*, based on facets of student knowledge that he had identified through research in his own classroom (Minstrell, 1988, 1992; Minstrell & Hunt, 1990). The students could work through a series of questions to diagnose their current thinking; then they could take next steps that the *Diagnoser* suggested based upon their responses. The diagnostic questions that begin each unit in this *Exploring Physical Phenomena* open-source textbook are a similar effort to alert the students and the

instructor to students' initial ideas about a topic, both those useful for building deeper understandings as well as any needing refinement. The first author's experiences here deeply influenced her adoption of a positive instructional perspective of helping students to expand their areas of competence rather than screening student responses for misconceptions that need to be corrected.

As an instructor in an innovative combined program for future teachers and future researchers at the University of California, Berkeley (Lowery, Schoenfeld, & White, 1990), the first author modeled video recording her own class sessions to gather data for doing research on one's own teaching practices and students' learning (van Zee, 2000). She enjoyed learning more about cognitive science along with her students, particularly through many conversations with Claire Bove, Ming Chiu, Miriam Gamoran, Sean Hutcherson, Lawrence Muilenburg, Marcelle Siegel, and Erica Street as well as with teaching colleagues Stan Fukunaga, Don Hubbard, and Dan Zimmerman. She learned about causal models from Professor Barbara White (1993) and about ways to use computers as learning partners from Professor Marcia Linn(1991). She also learned from Professor Andy diSessa (1993) about phenomenological primitives (p-prims), or pieces of knowledge that students may use in generating responses when asked physics questions. This perspective contrasts with interpreting students' responses as revealing misconceptions firmly embedded in students' brains, wrong ideas that need to be elicited, confronted, and changed. In addition, she learned from Professor Alan Schoenfeld (1992) about metacognitive processes that help students stay aware of what they are doing and why. These perspectives underlie this course's emphasis on explorations to expand and refine the prospective teachers' understandings of physical phenomena.

With expert mentoring from Professors John Layman, Randy McGinnis, and Jim Fey, the first author taught courses on methods of teaching science for prospective elementary and middle school teachers as a faculty member in the Department of Curriculum and Instruction at the University of Maryland, College Park. She also appreciated the warm welcome by Professor Joe Redish to activities in the Department of Physics. She noticed a distinct difference in students who were graduates of Physics 115, a course that served as one of the development sites for the American Association of Physics Teachers' *Powerful Ideas in Physical Science* curriculum (American Association of Physics Teachers, 1995; Ukens, Hein, Johnson, & Layman, 2004). Rather than being bewildered by her inquiry-based instructional approach, Physics 115 graduates understood what to do and seemed to enjoy doing it, modeling for their classmates learning science by working together asking their own questions and exploring phenomena without detailed step-by-step directions.

The first author enjoyed observing the Physics 115 course occasionally. She chose to adapt some light and thermal activities from this resource.

Collaboration with Professor David Hammer and a group of practicing elementary and middle school teachers broadened the first author's vision of what teaching science through inquiry can mean. Developed under NSF-9986846, *Case Studies of Elementary Student Inquiry in Physical Science* included engaging the teachers in learning physics during the summer as well as in documenting and interpreting their students' science thinking during the academic year (Hammer & van Zee, 2006). The emphasis was on recognizing and refining epistemological resources as well as initial science understandings (Hammer, 2000; Hammer & Elby, 2003). In teaching the physics course for prospective elementary and middle school teachers and preparing this open-source textbook, the first author drew on many of these experiences in the context of exploring light phenomena (van Zee, Hammer, Bell, Roy, & Peter, 2006).

Participating in the Carnegie Academy for the Scholarship of Teaching and Learning (Shulman, 2002) increased the first author's proficiency in video recording her own instructional practices and in writing interpretations of her students' thinking and learning. She also encouraged her students and graduates of her courses to document and interpret their own teaching practices and students' thinking and learning (van Zee, Lay & Roberts, 2003). This emphasis on focused reflection, based on evidence collected in class, underlies the extensive use of students' writing in preparation of this open source textbook.

The first author was invited to design this physics course for prospective elementary and middle school teachers after retiring from the University of Maryland and moving to Corvallis, Oregon. She deeply appreciates the welcome by Professors Larry Flick and Larry Enochs and the opportunity to collaborate with Rebekah Elliot, Nam Hwa Kang, and Janice Rosenberg in the Department of Science and Mathematics Education at Oregon State University. She learned a lot about teaching mathematics and using technology during a series of collaborations with Professor Maggie Niess.

The first author would like to thank Professor Fred Goldberg for his thoughtful encouragement as she grew more confident in teaching physics in interactive ways. The process of developing explanations in *Physics and Everyday Thinking* (Goldberg, Robinson, & Otero, 2007; Goldberg, Otero, & Robinson, 2010; Goldberg, Price, Robinson, Boyd-Harlow, & McKean, 2012) influenced the first author's design of assignments in this course. In starting to work on a physics problem, for example, students review the conceptual model they have developed for the relevant physical phenomenon before attending to the specific information provided. The *Physics and Everyday Thinking* curriculum's explicit

emphasis on learning about learning as well as learning about physics also influenced our attention to engaging students in developing pedagogical as well as physical science understandings as integral to class activities, homework assignments, and examinations.

The second author, Elizabeth Gire, also enjoyed talking with Professor Goldberg about interactive engagement strategies while he was teaching a course for prospective teachers with the *Physics and Everyday Thinking* curriculum. In addition, she was mentored by Charles De Leone in teaching an adaptation of CLASP (*Collaborative Learning through Active Sense-Making in Physics*), a course that supports students in building understanding by making observations, working in small groups to generate ideas, presenting those ideas to the rest of the class, and whole class discussion of those ideas (Potter, Webb, Paul, West, Bowen, Weiss, & De Leone, 2014). During that time, she studied how students' success on physics problems correlated with their use of non-algebraic representations (graphs, diagrams, etc) to make sense of physical situations and to communicate their understanding (DeLeone and E. Gire, 2006). Since then, her teaching and research has focused both on how students engage in physics sensemaking and how they use different representations to make sense of physical systems (Gire, Nguyen, & Rebello, 2011; Gire & Price, 2015; Hahn, Emigh, Lenz, & Gire, 2017).

Now a physics faculty member at Oregon State University, the second author is the current instructor for our physics course for prospective teachers and has been enriching this effort to create the *Exploring Physical Phenomena* open-source textbook. Her research focuses upon ways in which to engage students in seeking coherence among different representations of physics knowledge. She and her colleagues are developing a set of hands-on, discovery-style, discussion-based classroom activities that use dry-erasable three-dimensional plastic surfaces to represent physical systems that depend on multiple variables (Gire, 2017; Gire, A. Wangberg & R. Wangberg, 2018).

The second author also is developing a physics course for majors that explicitly engages students in developing knowledge of sense-making strategies, metacognitive skills, and productive beliefs about the nature of doing physics as well as in increasing their awareness and appreciation of physics sense-making processes (Gire, Emigh, Hahn, and Lenz, 2018). Her explicit focus on such physics education research contributes to her positive pedagogical approach in meeting the needs of the prospective elementary and middle school teachers, many of whom seem to perceive themselves initially as reluctant science learners. She has introduced circle conversations, for example, in which the small groups gather to share their findings, sometimes through multiple iterations of thoughtful discussions, until they come to consensus on their interpretations of what they have observed.

Both authors have enjoyed collaborating with Professor Corinne Manogue in the physics department's on-going research and curriculum development in the context of upper division courses for physics majors, *Paradigms in Physics* (Gire, Kustusch, & Manogue, 2012; Gire & Manogue, 2011; Manogue, Cerny, Gire, Mountcastle, Price, & van Zee, 2010; Manogue, Gire, & Roundy, 2013; Manogue & Krane, 2003; van Zee & Manogue, 2010, 2018). These courses are unusual in their organization of the physics content studied as well as in their use of interactive engagement strategies in class. Although the level of mathematics and conceptual content in the course for prospective teachers is different, the emphasis on encouraging students to enjoy learning with and from one another is similar. We both have grown in pedagogical as well as physics knowledge through our participation in the *Paradigms in Physics* program.

We are deeply grateful to the colleagues who have educated and encouraged us. We also have greatly appreciated the care and thoughtful assistance from Stefanie Buck, Dianna Fisher, Kenya Hazell, Baylee Bullock, Derek Ostrom, and Mark Lane of OSU Open Educational Resources. Our families also have been wonderfully supportive of this endeavor. However, any errors in these materials are our own. Please email us at vanzeeee@oregonstate.edu and/or giree@oregonstate.edu if you have suggestions for improving these materials.

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UNIT I: EXPLORING THE NATURE OF LIGHT PHENOMENA

Exploring Physical Phenomena: What happens when light from the Sun shines on the Earth?

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I. Introduction

This course is intended for prospective and practicing elementary and middle school teachers. By exploring physical phenomena in class, you will learn science in ways in which you are expected to teach science in schools or in informal settings such as afterschool programs, youth group meetings, and museum workshops. This course also is appropriate for general science students and others interested in exploring some of the physical phenomena underlying global climate change.

The theme for the course is: *What happens when light from the Sun shines on the Earth?* The emphasis is on questioning, predicting, exploring, observing, discussing, reading, and writing about what one thinks and why. This first unit focuses on exploring the nature of light phenomena. Among the unit's many goals are two primary ones: to learn about light phenomena and to learn about ways to foster science learning for yourself and others such as your family, friends, and students.

What does it mean to “explore the nature of light phenomena”? You will be:

- **identifying resources** such as positive experiences you already have had in learning about light and
- **developing central ideas based on evidence** that you record while exploring everyday phenomena such as light and shadows.

By central ideas, we mean understandings about physical phenomena that emerge from your discussions with your group members as well as with the instructor. These also are powerful ideas because they form conceptual models useful in:

- **explaining an intriguing phenomenon** such as what happens when you look through a pinhole camera, something most find surprising, yet even children can understand.

After developing conceptual understandings of the relevant physics principles, you will be:

- **developing mathematical representations** of this phenomenon and using these when
- **estimating a quantity of interest**, such as the diameter of the Sun.

Throughout the course you will be reflecting upon ways that are helping you learn science. In reflecting upon this learning process, you will be:

- **making connections to educational policy**, such as the *Next Generation Science Standards* (NGSS Lead States, 2013). This document has been adopted by many departments of education as the science standards for grades K-12 in the United States.

Other light phenomena that you will be exploring during this unit include reflection, refraction, and dispersion. You will develop additional central ideas based upon these explorations; then use this expanded conceptual model for light to explain another intriguing but more complex phenomenon: rainbows.

Because K-8 curricula emphasize learning to read and write well, this course also models ways to integrate science and literacy learning. By literacy learning, we mean learning to speak clearly, listen closely, write coherently, read with comprehension, and create and critique media.

The main sections present questions with suggestions for exploring topics and for writing reflections about your findings. The text in gray font indicates that these are suggestions; you may think of better ways to explore the topic. You are encouraged to ask and explore your own questions about light phenomena as well as those posed here. Check with your instructor if you choose to devise an alternative approach.

Keeping track of what one is doing and thinking is important. This course uses a physics notebook page that can organize how you record your notes during class. This physics notebook page can help you remember your thoughts *before*, *during*, and *after* an exploration. An experienced elementary teacher, Adam Devitt, designed this physics notebook page to mirror the structure of *before*, *during*, and *after* reading strategies:

Before starting your exploration, think about and discuss with your group members what you know already about this topic, how you plan to conduct the exploration, and what you think you might find out.

During your exploration, record what is happening, what you are observing, and what you are thinking about what you are observing. Include sketches of equipment and observations. Note any words that are new and their definitions.

After your exploration, record any central ideas that have emerged from your observations and discussions. Also note the evidence on which you have based these ideas. State explicitly how the evidence is relevant and supports the claims you are making in stating the central ideas. Also explain why this result is important. Then write a reflection

about whatever you want to remember about this experience. In addition, briefly state what you are still wondering in this context.

After class, use your physics notebook pages and any handouts to write a summary of your exploration and findings. Writing such a summary after every class is a good way to prepare for the midterm and final examinations.

Next, to be sure you have understood the physics involved, read this text and some examples of student work. The student authors first wrote drafts, received feedback for ways to enhance content and clarity, and submitted these final versions. Also read about some nuances to consider when explaining the phenomena explored.

You may also find helpful student reflections about teaching a friend or family member about what they had just learned in class, historical information about ways knowledge about the topic developed, and some relevant aspects of the nature of science in the context of the topic explored. These sections of the text may broaden your understanding of science and of science learning and teaching.

II. Identifying Student Resources

What do you already know about light? When did you learn this? Where were you? With whom? Why were you interested? How did this learning occur? These prior experiences in learning about light provide *resources* upon which you can draw in learning more about light in this course.

These “question words” –What? When? Where? Who? Why? and How? – represent an important aspect of science for which you are already expert in everyday life: asking questions. In this unit, you will explore questions that you and others generate about science learning in general and also about learning about light.

A. Learning about ways to foster science learning

Here is the first question:

Question 1.1 What have you learned about light at some time in your life, inside or outside of school, during an experience when you enjoyed the learning process?

Equipment for each small group: Use a piece of chart paper, magic markers (all colors), and some masking tape if there is room on a nearby wall to display your work.

- What did you learn about light? How did you learn this? With whom were you learning? Where were you doing this learning? When did this happen? Why were you enjoying this learning process?

Think about what you may have learned about light in a science class at school but also consider what you learned outside of school by playing with flashlights, looking in mirrors, swimming, wearing glasses, painting, seeing rainbows, sitting by campfires, growing plants, noticing the moon, watching a sunset, looking up at the stars...

If you are working with a group, share some of these learning experiences with one another.

- Choose one of these positive science learning experiences on which to focus. Draw a picture of yourself learning about light while enjoying the process. This course models integrating art and science so make a large vivid, colorful picture that will interest others.
- Note the age you were when you were learning this.
- While drawing a picture of yourself learning about light, think about why this experience had ‘worked’ for you. What had helped you learn about light in this instance?
- Add to your drawing words or phrases that convey some of the ways that this experience had helped you learn about light.
- If you are working with others, introduce yourselves by describing your positive experiences learning about light, the ages you were when you had these experiences, and some of the ways that these experiences had fostered your science learning.
- Based upon the evidence provided by this process, make a list of ways to help someone learn science in the context of learning about light.
- Make a claim about one way to foster such science learning. Support your claim with evidence drawn from the positive science learning experiences you and others reported.

After completing your exploration of ways to foster such science learning, look at an example of student work to see how others have thought about this process.

1. An example of student work identifying resources for fostering science learning

On the first day of class, for example, physics students in this course reflected upon their experiences in learning about light at some time in their lives, inside or outside of school, when they learned some science and enjoyed the process. Figure 1.1 shows some examples of positive science learning experiences that members of one group remembered and represented with drawings of ways in which they had learned about light.

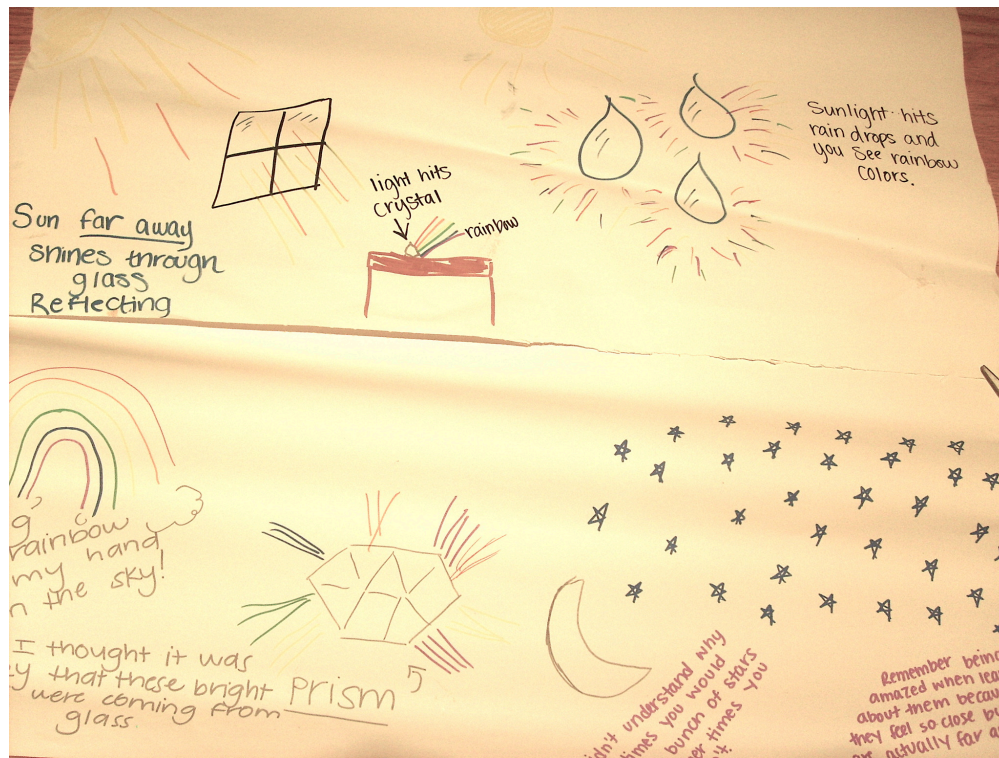


FIG 1.1 A small group's drawings of enjoyable experiences learning about light.

A student wrote about looking up at the stars, “didn’t understand why sometimes you would see a bunch of stars and other times you wouldn’t...Remember being amazed when learning about them because they feel so close but are actually far away.” Another student wrote, “Exciting to see rainbow colors in my hand and not in the sky!...I thought it was crazy that these bright colors were coming from glass.”

This array of experiences, drawn from multiple individuals, provides evidence upon which one can base claims. As shown in Fig. 1.2, students identified the following ways that had fostered their science learning: learning hands-on, access to books/resources, support from families, education, use of the environment: outdoor, camps, OMSI (Oregon Museum of Science and Industry), going to museums/planetarium, visual experiences, doing experiments, and asking questions.

Learning hands on
Books/Resources
Support = Families
Education
Environment = Outdoor
Camps
OMSI
Hands-on/Experiments
Resources
Nature/Environment
Museums/Planetariums
Visuals
Asking Questions

FIG. 1.2 List of ways to foster science learning identified by physics students.

This list is an example of findings from a qualitative study. The students based these findings on analyzing data that consisted of self-reported experiences by multiple individuals. The list forms an initial framework for thinking about ways to foster science learning. These ways “worked” for the individuals who generated the list and may help others learn science too.

The following is an example of a student making a claim and beginning to construct an argument to support that claim with evidence drawn from an array of personal experiences:

Claim: The use of the environment is an important aspect that fosters science learning.

Evidence: During the summertime I used to lay on a sleeping bag in my backyard

with my dad and we would watch the sky. I would spot stars, planets, the moon, and airplanes flying by. Observing my environment made me more aware and it got me to ask my dad questions about what was happening around us. Science is all around us, and using natural examples makes learning more exciting and more memorable.

Physics student, Spring 2015

This student began supporting her claim with an example drawn from a personal experience involving her home and family. Additional examples could strengthen this claim. Including group member's experiences of seeing rainbows, for example, could add support to this claim by illustrating other environmental contexts within which positive science learning occurred.

Your responses to Question 1.1. recorded some of what you already know about light and what you already know about ways to foster science learning. Next you will be documenting what you already know about the specific aspects of light that you are about to explore.

B. Documenting initial ideas about light phenomena

Question 1.2 is called a *Diagnostic Question (DQ)*. Your response to a Diagnostic Question documents what you already know about a particular topic. Your response will not be graded.

Question 1.2 What do you already know about looking at something like a ball?

Equipment: Place a ball near a lamp without a shade in a dark room.

- Find a ball or another object and place it near a lamp without a shade in a dark room so that you can see it well.
- How can you see the ball?
- How could someone on the other side of the room see the ball?
- Explain with words and a sketch

Diagnostic Questions: Science & Science Learning

How would you define a “scientific explanation”?

How would you define “inquiry approaches to learning and teaching”?

To what extent are you interested in learning science?

Not interested in learning science 1 2 3 4 5 Interested in learning science

Comment:

To what extent are you interested in teaching science?

Not interested in teaching science 1 2 3 4 5 Interested in teaching science

Comment:

Later in the course, you will respond to the same questions again. Hopefully you will know more! Then you can compare your initial and current knowledge about this topic and reflect upon what has been fostering your science learning in the context of this course.

III. Developing Central Ideas Based on Evidence

In this section, you will be developing some central ideas about the nature of light by playing with light and shadows. Keeping track of what you are doing and thinking is important.

A. Documenting your explorations

One way to document what you are doing and thinking is to write an on-going record in a science notebook. The physics notebook page shown in Figures 1.3 and 1.4, for example, can help you remember your thoughts *before*, *during*, and *after* an exploration. First view the front of the physics notebook page:

Topic: What are you exploring?

Before column. Before starting your exploration, discuss with your group members what you already know about this topic, what ideas you have, what questions you are asking, how you plan to conduct the exploration, and what you think you might find out. Record these briefly in the “Before” column along with any relevant drawings.

During column. During your exploration, record what is happening and what you are thinking about what you are observing. Include sketches of equipment and observations. Indicate whether you confirm or disconfirm your predictions and what these findings suggest for next steps.

Vocabulary. Note any words that are new and their definitions.

Then view the back of the physics notebook page:

After: Central Ideas. After your exploration, record any central ideas that have emerged from your observations and discussions.

After: Evidence. Also note the relevant evidence on which you have based these ideas.

After: Rationale. State explicitly how the evidence is relevant and supports the claim you are making in stating the central ideas. Also note why this result is important.

After: Reflection. Then write a reflection about whatever you want to remember about this experience – perhaps what you have done and learned, how you learned this, and what implications this experience might have for teaching this topic in your own classroom...

After: Wonderings. In addition, briefly state what you are still wondering at this point.

Adam Devitt designed these notebook pages when he was assisting in this course. He was a special education elementary school teacher enrolled in a graduate program in science education. He based his design of these physics notebook pages on “before, during, and after” reading strategies that enhance literacy learning. Some of the entries have been slightly modified.

Name:		Date:
Topic:		
Before <ul style="list-style-type: none">• Write what you already know• Note initial ideas• Describe what you want to try• Make predictions• Draw pictures	During <ul style="list-style-type: none">• Draw pictures of what you do• Record observations• Note emerging ideas• Confirm/disconfirm predictions• Describe what to try next	
Vocabulary		

After	
Central Ideas	Relevant Evidence
Rationale	
<div style="border: 1px solid black; padding: 10px; margin: 10px auto; width: 60%;"> <ul style="list-style-type: none"> Why is the evidence you have stated relevant? How does the evidence support the central ideas you have articulated? Why is this result important? </div>	
Reflection	
<div style="border: 1px solid black; padding: 10px; margin: 10px auto; width: 60%;"> <ul style="list-style-type: none"> What connections can you make to prior experiences, out-of-school experiences, NGSS? What helped you learn during this activity? What could you have done differently? What did you like/dislike? What would you like to share with others? How might you use what you learned in your own classroom? </div>	
What am I still wondering?	

FIG. 1.3 Front and back of physics notebook page with explanations

Name:	Date:
Topic:	

Before:	During:
----------------	----------------

Vocabulary

After	
Central Ideas	Relevant Evidence
Rationale	
<hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/>	
Reflection	
<hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/>	
What am I still wondering?	

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FIG. 1.4 *Physics notebook pages template*

B. Exploring the nature of light phenomena

Asking questions is an important aspect of *doing* science. Question 1.3 is a “what happens...” question:

Question 1.3 What happens when light from a source shines on a screen?

Equipment: a light source in a dark room; a screen such as a large white board covered with a piece of chart paper

- Find a dark room in which to explore the nature of light such as a room with no windows or a room with windows that have dark shades to keep out daylight.

For a vertical screen, use a plain white wall or make one by taping a piece of chart paper on a whiteboard or large piece of cardboard that you can lean against a stool or box on a table.

For a *light source*, use a lamp without a shade, that has a clear unfrosted incandescent bulb or a frosted bulb with LEDs.*

(*Look at the inside of the incandescent bulb. The narrow wire inside the bulb is called its *filament*. The filament is made out of a metal that glows when electricity flows through the lamp. LEDs (light emitting diodes) emit light by a different process that requires much less energy. LEDs have been marketed in a frosted bulb to imitate light from incandescent bulbs.)

- Place the lamp near the screen. Figure 1.5 illustrates the set-up.

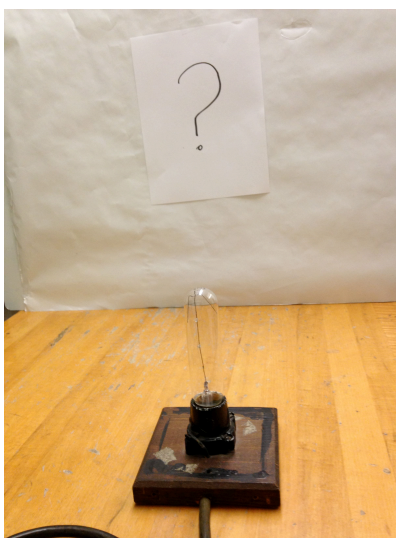


FIG. 1.5 Predict what you will see when turning on a clear light bulb near a screen.

- What will you see on the screen?
- Talk with your group members about what you think and why you think that.
- Begin to keep track of what you are doing: At the top of your physics notebook page, record the *Topic* of this exploration.
- Under *Before*, draw a picture of the set up. What do you predict will happen? Why do you predict this will happen?
- Turn on the light bulb in the dark room: what do you see on the screen?
- Under the *During* section of your physics notebook page, record what you see and interpret these results.
- Discuss your findings and formulate a relevant central idea. In the *After* section of the physics notebook page, report this idea and the evidence on which it is based.
- Use this physics notebook page and additional pages as needed to keep track of what you are doing and thinking during a series of related explorations.

In summarizing this exploration, a student noted, for example:

The demonstration started with a vertical light bulb being placed in front of a white piece of paper. We made predictions about what we thought would happen when the

light was turned on in a dark room and I thought that the light would make a circle on the white paper, which gets dimmer as the circle gets bigger.

Some students predict that they would see light in the shape of the filament on the screen. A student reported:

When a lamp is turned on in a dark room, light from the lamp shines on a screen. If the light source is a clear incandescent bulb, the light on the screen is not limited to the shape of the filament. The area of the screen directly in front of the lamp may appear brighter than areas of the screen farther away from the lamp, but all of the screen is lit. In addition, light from the lamp shines on the ceiling and the other walls of the room, as well as on the faces of those looking at the lamp and screen.

This suggests a central idea, that **light leaves a source in all directions**. A student may note, however, that light leaves lasers in a particular direction. A further refinement involves pondering the use of *all*, whether one can be sure that light leaves a source in every direction. This suggests that **light leaves most light sources in many directions**.

Have you ever used your fingers to make shadow shapes when playing with a flashlight in a dark room? Question 1.4 poses another “what happens?” question.

Question 1.4 What happens when you place a barrier between a lamp and screen?

Equipment: Find a *barrier* of some kind to add to your set up. This can be a card or a book that can stand up on its edge or even just fingers on your hand.

- Predict what you will see when you place the barrier between the lamp and screen as shown in Fig. 1.6.



FIG. 1.6 Predict what you will see when placing a barrier in front of the screen.

- Place a barrier between a lamp and a screen: What do you see on the screen?
- Try a variety of ways of placing the barrier with respect to the lamp and screen. Making different shadows with a barrier can be a lot of fun! What do you observe?

Another kind of question asks “how” something is happening:

Question 1.5 How does light seem to travel from a source to a screen?

A meter stick or yard stick is a useful tool to explore how light travels from one place to another:

- Use a straight stick such as a meter stick or yard stick to explore how light gets from the lamp past the barrier to the edge of a shadow on the screen.
- Keep talking and refining ideas until your group and the other groups reach a consensus on several central ideas about light and shadows based on this exploration.

For example, here is what one student reported seeing:

We had a white piece of paper against the wall with the bottom of the paper touching the table. There was a light bulb set up to shine light toward the paper. There was a wooden block set up in front of the white paper and when the light bulb shined upon the block, the light was obstructed and as a result a shadow of the block was produced on the screen.

We placed one end of a meter stick on the side of the light bulb; then we placed the meter stick against the edge of the wooden block and finally placed the opposite end of the meter stick against the white paper.

We observed that the edge of the shadow, the edge of the wooden block, and the side of the light source all lined up in a straight line.

This suggests that **light can be envisioned as rays traveling in straight lines.**

Figure 1.7 shows an example of using a straight stick as a *physical model* for how light can be envisioned as rays traveling in a straight line from a light source past the edge of a barrier to the edge of a shadow on a screen.



FIG. 1.7 A straight stick can provide a physical model for how light travels.

Looking closely at a lamp and barrier setup suggests Question 1.6, a “how many?” question:

Question 1.6 *How many shadows are there when a light source shines on a barrier and screen?*

- Look at both sides of the barrier as well as at the screen.
- Keep talking and refining ideas until your group and the other groups reach a consensus about how many shadows there are when a light source shines on a barrier in front of a screen.

Here is what one student reported:

The first shadow that I observed was one on the white piece of paper. When an object was placed in front of a white piece of paper with a light shining on it, the object's shadow was seen on the nearby piece of paper. The second shadow that I observed was on the back side of the object. The back side of the object...was dark and had a shadow on itself.

Physics Student, Spring 2016

This suggests another central idea about light and shadow phenomena as shown in Fig 1.8: **There are two kinds of shadows: An object blocks light a) from shining on a nearby surface (ground, table, wall, screen) and b) from shining on the back side of the object itself.**

A student supported this idea as follows:

An argument based on evidence to support this idea is that a shadow was seen on the piece of paper, which is the object blocking light from hitting the nearby surface, and a shadow was seen on the back side of the object which was the object blocking light from hitting the backside of itself, which shows that there are two different kinds of shadows created by an object.

Physics Student, Spring 2016



FIG. 1.8 Two kinds of shadows are formed when a barrier is placed between a light source and screen

Question 1.7 introduces an open-ended question that invites you to explore additional light and shadow phenomena by yourself, with a small group of colleagues, and/or with friends and family members:

Question 1.7 What can you find out about light and shadows with a lamp, barrier, and screen?

Equipment: Play with lamp, barrier, and screen to find out what else you can learn about light and shadows.

- Describe your explorations, evidence from your observations, central ideas about light and shadows that you infer from these explorations, the argument that supports those ideas and any relevant vocabulary.
- Reflect upon what you have learned and what you are still wondering.
- Write a summary of the central ideas based on evidence that emerged from the small group conversations and whole group discussion.

A useful way to organize outcomes from a series of explorations is to summarize them in a table as in Table I.1.

TABLE I.1 Explorations of light phenomena

TABLE I.1 Explorations of light phenomena			
Description of Exploration	Evidence Observed	Central Ideas	Vocabulary
		Light leaves most sources in many directions	
		Light can be envisioned as rays traveling in straight lines	
		There are two kinds of shadows: An object blocks light a) from shining on a nearby surface (ground, table, wall, screen...) and b) from shining on the back side of object itself	
		*	
		*	

TABLE I.1 Explorations of light phenomena

TABLE I.1 Explorations of light phenomena			
		*	

* Central idea(s) about light and shadows developed during exploration with group members and/or friend/family

During class, some groups decide to explore what happens when they move the barrier closer or farther from the light source. Others choose to move the light source. A whole group discussion of their findings suggests another central idea:

Changing the position of the barrier with respect to the lamp and/or the screen, changes the size, shape, and sharpness of the shadow on the screen.

This completes our initial exploration of the nature of light phenomena. Based on the evidence from your observations, summarize the central ideas that you have inferred about:

- How does light leave most light sources?
- How can light be envisioned as traveling from one place to another?
- What kinds of shadows form when light shines on an object?
- What influences the size, shape, and sharpness of a shadow on a screen?

These ideas form a *conceptual model* that you can use to explain interesting phenomena you observe during additional explorations.

After summarizing your explorations in class, enjoy some students' reflections on teaching friends and children about light and shadows.

Question 1.8 What happens when exploring light and shadows with a friend or family member?

1. Examples of students' explorations of light and shadows with friends and/or family members.

A student reported:

During this exploration my friend and I began by discussing the previous ideas. When talking about light and shadows, we began to talk about how when we were younger we could use light to create shadow puppets with our hands. We decided to get out a lamp, turn the lights off, and use the light to create shadows onto the ceiling. During this exploration we noticed how the closer our hands were to the light source the shadow of our hand on the ceiling was bigger, and when we moved our hands further from the light source our shadows would become smaller and more defined. During this exploration I learned that as the one teaching the concepts and ideas I can also be learning and exploring with my students, the activities can be guided by both the student and the teacher experiences.

Physics Student, Spring 2016

Another observed the following when exploring shadows with a friend:

When exploring shadows, my friend and I took a particular interest in the effects of having more than one light source when facing the barrier. Introducing a new light source from a new position in the room changes both the area and the position of the shadow that the barrier is making, depending on which way it is facing.

Physics Student, Fall 2015

One student chose to explore all of the set of central ideas we had developed in class with three children whom she babysat. This was more than expected but a delightful example of a prospective elementary school teacher gaining experience teaching what she had just learned herself in class. She chose to use the initial version of the first central idea with these young children. Her verbatim quotes provide an excellent window into what preschool and elementary age children know, think, and wonder about light:

While working on this project I enlisted the help of three girls that I babysit. The ages of these girls are as follows: Lucie-7, Ava-4, Ruby-4. The names of these girls have