Teacher's Edition

IQWST

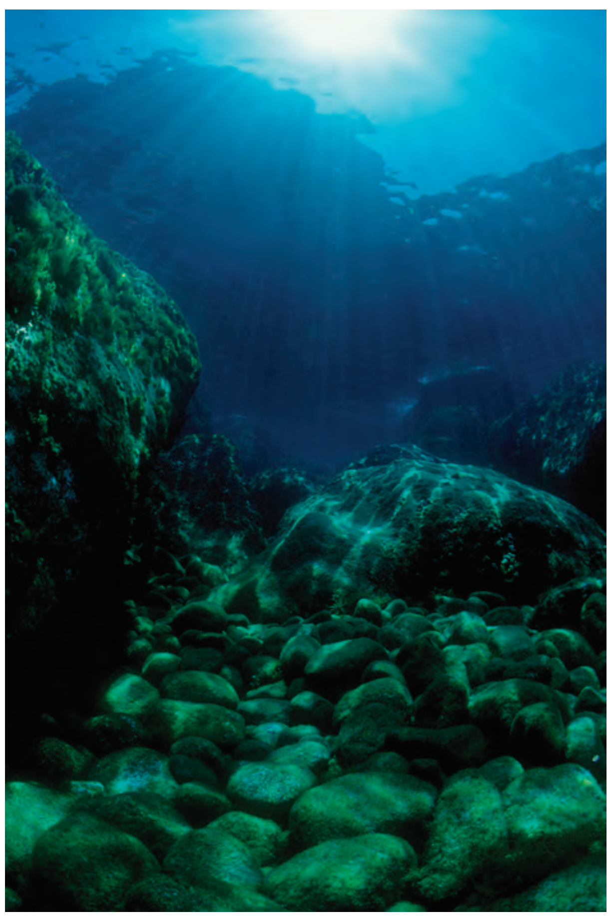
Physical Science

Can I Believe My Eyes?

Second Edition

CAN I BELIEVE MY EYES?

Light Waves, Their Role in Sight, and Interaction with Matter



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Investigating and Questioning Our World through Science and Technology (IQWST)

CAN I BELIEVE MY EYES?

Light Waves, Their Role in Sight, and Interaction with Matter

PHYSICAL SCIENCE

Teacher's Edition
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Can I Believe My Eyes?
Light Waves, Their Role in Sight, and Interaction with Matter

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About the Publisher

Sangari Active Science Corporation is a mission-driven company that is passionate about STEM education. We make it easy for teachers to teach with quality, investigation-centered science curriculum, tools, and technology. For more information about what we do, please visit our website at http://www.sangariglobaled.com.

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PS1 CONTENTS

ART

Every effort has been made to secure permission and provide appropriate credit for the photographic materials in this program. The publisher will correct any omission called to our attention in subsequent editions. We acknowledge the following people and institutions for the images in this book.

Lesson 1

Optical Illusion 2 – *Wikipedia, The Free Encyclopedia*

Lesson 3

Solar Sail – National Aeronautics and Space Administration, U.S. Government

Lesson 6

Hardwood Pores – *Wikipedia, The Free Encyclopedia*

Lesson 13

Satellite Photograph of Earth – Courtesy National Oceanic and Atmospheric Administration, U.S. Department of Commerce

IQWST OVERVIEW

IQWST is a carefully sequenced, 12-unit middle school science curriculum, developed with support from the National Science Foundation. As designed, each academic year includes four units, one in each discipline: Physics, Chemistry, Life Science, and Earth Science. IQWST's foundation is the latest research on how students learn and how they learn science in particular. At its core, IQWST engages students in scientific practices as they experience, investigate, and explain phenomena while learning core ideas of science. Rather than memorizing facts, students build understanding by connecting ideas across disciplines and across the middle grades. The following are key components of IQWST, important whether following NGSS, the Framework, or individual state standards.

Core Ideas: Focus on a limited number of core science ideas, aiming for depth of understanding rather than the superficial coverage inherent when aiming for breadth.

Scientific Practices: Engage meaningfully in science and the work of scientists through eight practices, used singly or in combination to explore and learn core ideas *in each lesson*.

Crosscutting Concepts: Thread throughout the curriculum the seven cross-disciplinary concepts, repeatedly revisited such that students construct deep understanding of the ideas as they apply to each science discipline.

Coherence: Build understanding through a progression within each grade level and across grade levels. Learning critical concepts and practices across content areas and grades provides students with opportunities to develop, reinforce, and use their understandings on an ongoing basis throughout their middle school years.

Performance Expectations: Identify *how* students engage with a specific practice in order to learn a specific core idea and to build increasing understanding of a broader crosscutting concept.

THE IQWST UNIT SEQUENCE: BUILDING COHERENCE

Although IQWST units can be enacted in a manner that meets district needs, they are designed based on research that shows the importance of coherent curriculum, structured such that students build understanding as they revisit ideas across disciplinary strands, content, and grade levels and deepen their understanding across time. The *Framework* indicates, "Standards should be organized as progressions that support students' learning over multiple grades. They should take into account how students' command of concepts, core ideas, and practices becomes more sophisticated over time with appropriate instructional experiences" (NRC 2011).

The role of coherence in materials and instruction is well documented: Most science programs (textbooks and instruction) do not support deep, integrated student learning because they lack coherence (Kesidou & Roseman, 2002; National Research Council, 2007). Yet presenting interrelated ideas and making connections between and among them explicit (Roseman, Linn, & Koppal, 2008) was found to be the strongest predictor of student outcomes in the Trends in International Mathematics and Science Study (TIMSS) (Schmidt, Wang, & McKnight, 2005).

Curricular coherence is best accomplished through teaching the ideas in IQWST units in a recommended sequence. That sequence aligns with NGSS, which treats a core idea such as "energy," for example, as both a Crosscutting Concept and a Core Idea. In IQWST, students engage with ideas about energy in the first physical science unit of the sequence and then revisit energy concepts in life science, chemistry, and Earth science—and in later physical science units—so that as students apply energy ideas to new content and contexts, their understanding of one of the most challenging concepts in science education deepens across middle school.

The following chart illustrates the recommended sequence for optimum curriculum coherence, enabling students to build on and revise their understanding of core content and to strengthen their ability to successfully engage in scientific practices over multiple years.

IQWST MIDDLE SCHOOL CURRICULUM

Level 1	Physical Science	Introduction to Chemistry	Life Science	Earth Science
	Can I Believe My Eyes? Light Waves, Their Role in Sight, and Interaction with Matter	*How Can I Smell Things from a Distance?* Particle Nature of Matter, Phase Changes	*Where Have All the Creatures Gone?* Organisms and Ecosystems	*How Does Water Shape Our World?* Water and Rock Cycles
Level 2	Introduction to Chemistry	Physical Science	Earth Science	Life Science
	How Can I Make New Stuff from Old Stuff? Chemical Reactions, Conservation of Matter	*Why Do Some Things Stop While Others Keep Going?* Transformation and Conservation of Energy	*What Makes the Weather Change?* Atmospheric Processes in Weather and Climate	*What Is Going on Inside Me?* Body Systems and Cellular Processes
Level 3	Earth Science	Life Science	Physical Science	Introduction to Chemistry
	How Is the Earth Changing? Geological Processes, Plate Tectonics	*Why Do Organisms Look the Way They Do?* Heredity and Natural Selection	*How Will It Move?* Force and Motion	*How Does Food Provide My Body with Energy?* Chemical Reactions in Living Things

UNIT STRUCTURE

Driving Questions

Each IQWST unit focuses on a Driving Question, which is also the unit's title. A Driving Question is a rich, open-ended question that uses everyday language to situate science content in contexts that are meaningful to middle school students. As each unit progresses, the phenomena, investigations, discussions, readings, and writing activities support students in learning content that moves them closer to being able to answer the Driving Question in a grade-appropriate manner.

Learning Sets

IQWST lessons are grouped into three to five learning sets per unit, each guided by a sub-question that addresses content essential to answer the Driving Question. This structure unifies lessons and enables students to meet larger learning goals by first addressing constituent pieces of which they are comprised.

IQWST lessons support research-based instructional routines with several components designed and structured to meet teacher needs. Each lesson comprises multiple activities (i.e., Activity 1.1, Activity 1.2) that altogether address one to four Performance Expectations (as described in NGSS). Each lesson is preceded by lesson preparation pages, Preparing the Lesson, as described in the following Lesson Structure section.

LESSON STRUCTURE

Each IQWST lesson contains common components to support teachers as they progress through the unit's activities.

Preparing the Lesson

The information on the first pages of each lesson supports the teacher in previewing and preparing for the lesson.

Teacher Background Knowledge

This section describes content to be addressed in the lesson, specifics about use of language or measurement tools, and prerequisite knowledge students are expected to have. If IQWST units are taught in the designed sequence, prerequisite knowledge is that which is expected from elementary school. If IQWST units are taught in an alternative sequence, this section alerts teachers about what students will need to understand in order to make sense of activities in a unit and to achieve its learning goals. This section also addresses content that may lie outside of teacher expertise in order to support teachers in working with content with which they are less familiar.

Sometimes, a Common Student Ideas heading describes ideas from research on misconceptions or describes other difficulties students have been shown to have with the content of a particular lesson. The section may describe prior knowledge that does not align with accepted science and that may be a stumbling block to understanding.

Setup

Setup is noted on the preparation page when the teacher needs to prepare materials ahead of time, such as mixing solutions, premeasuring materials for student groups, or setting up stations.

Safety Guidelines

A section on safety is included in the IQWST Overview. Within units, safety guidelines specific to a lesson are sometimes described separately so as to call attention to them. Examples include how chemicals should be handled and disposed of or when wafting is necessary rather than inhaling substances.

Differentiation Opportunities

Differentiation ideas highlighted prior to a lesson specify ways to either go beyond the performance expectations for the lesson or to support students who need additional help with content. Differentiation strategies that can be applied across lessons are described elsewhere in this Overview.

Building Coherence

This section briefly situates the lesson in those that precede and follow it and often references content students will have encountered in previous IQWST units, if units have been enacted in the recommended sequence.

Timeframe (Pacing)

This note estimates the number of class periods the lesson will take to complete based on widespread classroom experience. Richer discussions, more time spent on reading or writing skills, enacting demonstrations as group activities or vice versa, and other teacher-chosen adaptations require adjusting the timeframe. Most lessons require two or more class periods, as most are composed of multiple activities. Pacing is based on 50-minute class periods. Longer or shorter periods, or block schedules, require adjustment so that each class session is a coherent whole. Suggested pacing is also noted on the Unit Calendar located in the front matter.

Overview

A succinct list provides a snapshot of primary activities within a lesson, identified by activity number (i.e., Activity 1.1, Activity 1.2).

Performance Expectations

Performance Expectations describe what students should *know* and *be able to do* in a given lesson. Performance expectations describe one or more scientific practices in which students will engage in order to learn a disciplinary core idea, often also addressing a crosscutting concept, such that teachers can effectively plan, focus, and assess students' understanding.

Materials

These sections list the supplies required to carry out each activity within a lesson. They are quantified and grouped based on teacher needs, group needs, and individual needs.

Introducing the Lesson

This feature is included when activities are specifically designed to launch a lesson, often including integration of the previous reading or homework assignment.

Discussion Types

Types of discussion are described elsewhere in this Overview and are identified within each activity: Brainstorming, Synthesizing, or Pressing for Understanding. Each discussion has a stated purpose, followed by suggested prompts to guide conversation. Prompts are not intended as a script but provide teachers with alternatives they can use or from which they can shape their own questions—both factual/close ended and open ended to encourage thinking, challenging, explaining, and arguing from evidence.

Reading Follow Up and Introducing Reading

Suggestions for introducing and following up reading aid comprehension, retention, and integration of reading into science lessons. Readings are designed to be done independently, as homework, providing students with opportunities to revisit class activities, to connect science to their everyday lives, to deepen their understanding of content, and to apply their understanding to new examples and contexts. The pacing of lessons, as described, presumes that reading is not an in-class activity but is an at-home activity to extend student learning. Reading is addressed more fully elsewhere in this Overview.

Teacher Supports

Icons

Apple – Signals an "aside" to the teacher, often a strategy or a hint about student thinking likely to arise during an activity. Strategies and hints are embedded at points in the lessons that are most helpful to the teacher.

Checkmark – Signals a point at which the teacher should stop and check students' understanding before moving forward in the lesson or unit. Often, the ideas accompanied by this icon can be used as assessment opportunities.

Open Book – Signals either a reading assignment or a follow-up homework activity at the point in a lesson that it is best assigned. Typically the book icon is at the end of an activity and indicates work that is to be done in preparation for the activity that follows.

Safety – Signals precautions important to ensure safety in a lesson. Many lessons do not have specific safety precautions; instead, the lesson directs the teacher to the Overview, where general precautions, to be followed across IQWST lessons, are outlined.

Key – Signals smaller-scale learning goals that may be components of a larger disciplinary core idea. Key ideas might also include scientific principles derived from class activities, important definitions, or a new type of X to be added to a list of "types of X" students have been compiling in the unit. Key ideas might include main ideas at which students should arrive after an activity, reading, or class discussion.

Probe – Signals that technology is used in a particular lesson either for modeling (e.g., a computer simulation) or for quantitative measurement (e.g., probes and data loggers).

Pencil (only in Student Edition) – Signals places in which a written response is expected. Because questions are used as headers and are also woven throughout readings to engage students as active readers, an icon is used to indicate when a written response, rather than simply "thinking about," is required.

Projected Images (PI)

The value for students of seeing images in science cannot be overestimated. Projected Images (PI) are to be displayed for the class. Selected images may be printed for display on the Driving Question Board and perhaps laminated for reuse.

Each IQWST lesson includes projected images, charts, and graphs to expand students' understanding of science concepts. These colorful images are most effective for instruction if they are displayed in the front of the room on the white board. The images are located on the IQWST Portal in each unit folder, and all are named clearly.

The IQWST Portal

The IQWST Portal is an online resource for educators and students to access IQWST curriculum resources, including teacher editions of IQWST textbooks, student lab books, unit materials lists, assessments, and more. The IQWST Portal also provides access to digital resources including lesson-specific videos and audio files with narration of every student reading. Interactive resources and simulations like NetLogo are also located on the IQWST Portal.

The IQWST Portal is organized with each of the 12 units listed as a course. Within each course the content is divided into learning sets that are composed of multiple lessons. Within the lessons, educators can access digital versions of IQWST print materials, digital resources, and interactive resources. Each unit also contains a news section with up-to-date links to articles and research relevant to physical science, chemistry, life science, and Earth science.

DIFFERENTIATION IN IQWST

Range of Student Learners

Strategies built into IQWST lessons acknowledge students' differing capabilities, expectations, experiences, preferred learning styles, language proficiency, reading strategy use, and science background knowledge, among others. Materials address diverse needs by connecting classroom science to students' everyday, real-world interests and experiences. Each activity provides opportunities for teacher guidance, for independent work as well as small-group and whole-group interaction, for investigation, for discussion, and for reading, writing, and talking science. Opportunities for differentiation abound in each of these areas and in each lesson, so all students can work at their appropriate level of challenge.

Activity-based experiences enable students to share common experiences from which to build understanding. Students with kinesthetic preferences can use their strengths as doers and problem solvers. Those with verbal preferences can talk and write about processes and practices and can contribute ideas from readings to the discussion. Those with tactile preferences can manipulate materials. Those with visual preferences observe rather than only read about science. IQWST does not require memorizing definitions, writing paragraphs using vocabulary, or writing lab reports. Students with a range of learning preferences, language abilities, and other strengths and weak areas as learners can contribute to, engage in, and learn from each investigation—independently and collaboratively.

Specific differentiation opportunities are described in the Preparing the Lesson pages that precede each lesson. The following general strategies apply across IQWST.

General Differentiation Strategies

- Students begin each unit with an activity to generate original questions that will form the Driving Question Board (DQB) for the unit. Some of their questions will not fit into any of the categories used to organize the DQB and will not be addressed in the unit. Such questions may be assigned to students as an ongoing, individual project that they complete using various resources.

  - Such projects enable students who benefit from "going beyond" the unit to do so independently. With the teacher's discretion, projects for advanced students might come from such work, requiring use of multiple resources with varied text complexity.
  - Passionate interest has been shown to motivate students who struggle with reading to nonetheless read texts well beyond their Lexile level or presumed "ability" in a quest to learn more about something they are invested in. English Learners, students with learning disabilities, and struggling readers should thus be encouraged to investigate topics in which they are keenly interested. Some students will need support with resources (e.g., Internet search terms or suggested websites), but it is important to encourage all students to pursue areas of interest.

- Two follow-up questions that students cannot get wrong, simply by virtue of having read are (1) What did you find most interesting about last night's reading? and (2) What is one new thing you learned as you read last night's assignment? Some variation of either of these questions can be used for accountability purposes (i.e., Did the student read?) and for encouragement purposes (i.e., There are no wrong answers).

- Discussion is important to allow exchange of ideas and examination of one's own ideas. Many students, especially English-language learners, students with learning disabilities, or students with auditory processing difficulties, struggle to make sense of a question and formulate a response in time to raise their hands and articulate their ideas orally. For such students, consider a think-pair-share strategy. Pose a question and provide students with time to *think* about their response (or to write their ideas). Then, *pair* students with partners to *share* ideas. The teacher can then call on a pair, who can give a response they have had time to rehearse. This activity can be taken a step further to *square* the response by having two pairs talk together.

- Some students participate more fluently and comfortably if they are sometimes told ahead of time which question they are going to be asked to share their ideas about. Preparation time allows them to jot notes, to practice orally, or to reread a written response and be confident about sharing aloud. A teacher can prepare a sticky note such as "Be ready to talk about your answer to Question 3," and can place that note on a student's book in the course of teaching a lesson. This enables students with a range of language proficiencies, background knowledge, memory, or ability to process information time to think through their ideas and thus to be more confident and successful sharing in whole-class contexts.

Reading Differentiation Strategies

- Readings are designed based on research indicating that when students are passionate about a topic they often read well beyond their determined "reading level." Thus, IQWST readings emphasize engaging students in science. In many programs, reading level is simplified by shortening sentences and using easier vocabulary. However, doing so shortchanges students in two ways. First, shorter sentences require removal of connecting words (therefore, so, then) that actually support comprehension. Second, simplifying text by limiting multisyllabic words shortchanges students by ensuring that weaker readers remain unable to engage with texts that use the vocabulary of science. Therefore, IQWST does not differentiate with simplified materials but with strategies that support readers to learn all they can from the texts provided.

- IQWST lessons provide strategies for introducing reading, monitoring student comprehension, and following up on reading assignments. A Getting Ready section begins each reading as a research-based strategy for improving comprehension—the sections generate interest and engage students, activate prior knowledge, and provide a purpose for reading. Although these strategies support all students, struggling readers can be explicitly taught the value of each of these components as strategies successful readers use to improve comprehension. Strong readers, often unknowingly, "wonder" about what they are about to read, thus providing a purpose for reading that improves their comprehension and retention.

- Reading in science contains both main ideas and important details. Some IQWST readings employ methods for students who need to continue to work on reading strategies with built-in prereading strategies and advance organizers to help students with both text structure and content. Teachers may create additional advance organizers, as desired for particular readings.

- Encourage students to read all of the written material, as it is designed to support learning of key concepts, and to extend the application of key ideas into the real world thus to generate interest in science. However, many options enable the teacher to support struggling readers, students with learning disabilities, English Language Learners, and advanced students.

    - If students find an assignment overwhelming, let them know what to focus on as they read, perhaps indicating (or marking) two or three sections of the reading that they should read carefully. Doing so gives them freedom to read all of the material but focuses their reading so that they are more likely to experience success when they can participate in follow-up class discussion because they focused on the "right" section of the reading.
    - When a reading has multiple examples (e.g., a reading about how the eyes of three types of animals work), invite students to prepare to talk about any one of the three. Doing so does not erase the opportunity to read all but enables students to make choices and to focus their reading, providing encouragement and small steps toward success.
    - Many opportunities exist for advanced students to conduct Internet searches and read more complex texts as they either pursue areas of interest or are assigned such work by the teacher.

- Support readers by pre-identifying challenging language in the readings. On the board, write 2-3 words likely to be stumbling blocks, pronounce them, and provide connections (if possible) to everyday use of such words or to cognates for English-language learners (e.g., consulting an English/Spanish science glossary). IQWST is built on a strong research base showing that the best way to learn vocabulary is to encounter and use words in context. Use an interactive Word Wall to display words so that they may be referred to often. Pre-identifying and pronouncing words that might cause difficulty is not meant as a strategy for teaching vocabulary but only as a way to ensure that when students encounter Leonardo da Vinci's name or see "optical illusion" in print, they will not experience unfamiliar words as roadblocks.

- Readings should be previewed and followed up in class, and soon most students, even struggling readers, will attempt at least portions of the reading. Even if they do not read the entire assignment, or do not read well, students will make sense of whatever they do accomplish in ways that will help them learn. IQWST is not a textbook-driven curriculum, so using class time to read the materials does not align with a project- and inquiry-based philosophy in which students experience phenomena and then think about, write about, talk about, and read about science to learn content in meaningful ways. Encourage reluctant readers by asking follow-up questions that draw on examples from the reading, making the focus not on details, but on sense making, so that all can feel successful and encouraged to read.

Writing Differentiation Strategies

- Writing in science must be clear and accurate. For students with motor skills difficulties, provide ample writing space by using the margins, the back of the page in the student book, or additional paper. Students can also write on a computer, print, and paste the page into the student book.

- To support students with learning disabilities, who may omit words in writing, suggest that they read their own writing aloud, as they can often "hear" omissions when they do so. Alternatively, a peer or family member can read a written response aloud to allow students to self-correct as they hear errors in their writing. Another person may also scribe while students who struggle with writing provide oral responses, allowing students to express their understanding of science ideas and to communicate more successfully.

Mathematics Differentiation Strategies

- Measurements in science are precise, and measuring using science equipment can be difficult. Collaborative investigations enable students with varied strengths to work together. Although all students should learn how to use the tools of science, students who have difficulties with motor skills or vision impairments, for example, do not need to physically measure or be the person solely responsible for reading the thermometer. Instead, students work together to carry out investigations.

- Procedures in science require a sequencing of steps that can be difficult for some students if instructions are given only orally or only in print. To support all students, review written instructions orally, step-by-step, as needed. Have students reread procedures even after they have been reviewed. Demonstrate procedures for investigations that are anticipated to cause confusion or frustration. Many students are more successful if they check off steps as each is completed.

SCIENTIFIC AND ENGINEERING PRACTICES

The *Framework* and NGSS identify eight practices that build and refine scientific knowledge and thus are central to the scientific enterprise. Rather than separate content knowledge and inquiry skills, as in previous versions of national standards newer standards move toward combining core content and scientific practices in tandem. IQWST is based on the same extensive research that forms the foundation of science education for the 21st century and the basis for the *Framework* and NGSS. Thus, IQWST lessons integrate and continually reinforce practices such that students develop greater facility with and deeper understanding of these practices and of the content they address, whether NGSS, the Framework, or state standards guide learning.

Engaging in scientific practices enables students to experience how it is that scientists come to particular understandings rather than to experience science as a set of complete, discrete, isolated facts. In addition, a focus on practices, as an extension of previous approaches to inquiry, expands students' understanding of science beyond viewing it as a limited set of procedures or as a single approach typically characterized as "the scientific method."

Scientific practices require both knowledge and skill, and IQWST approaches scientific practices in that manner; they are always contextualized. Rather than a lesson about "how to construct a good scientific explanation," explanations are taught in the context of a lesson about core content using the construction of an evidence-based explanation as a way to think about, make sense of, and communicate one's understanding of phenomena. All eight practices are reflected throughout IQWST. However, each unit's learning goals emphasize particular practices, emphasizing those best taught (and practiced) in the context of a given unit's learning goals and investigative activities.

- Asking Questions and Defining Problems
- Developing and Using Models
- Planning and Carrying Out Investigations
- Analyzing and Interpreting Data
- Using Mathematics, Information and Computer Technology, and Computational Thinking
- Constructing Explanations and Designing Solutions
- Engaging in Argument from Evidence
- Obtaining, Evaluating, and Communicating Information

Each of these is addressed individually in sections that follow.

Scientific Practice 1: Asking Questions and Defining Problems

A key IQWST instructional component is each unit's Driving Question. A driving question is a rich, open-ended question that uses everyday language to situate scientific principles in contexts that are meaningful to middle school students. The discussions, investigations, science readings, and writing activities all relate to the Driving Question. IQWST involves students in constructing, evaluating, communicating, and reaching consensus on scientific explanations of how and why phenomena happen. In order to engage in this practice, students must make sense of phenomena they study and then articulate and defend their understandings to themselves, each other, the teacher, and other audiences. As each unit progresses, students learn content that moves them closer to being able to answer the Driving Question in a grade-appropriate manner. As important, each unit purposefully solicits students' original questions and provides the teacher with guidance about posting those questions on a Driving Question Board in the classroom and integrates them into the lessons. Thus science becomes "what I wonder about" rather than only "what I am told I should think about."

In addition, in the process of exploring phenomena and wondering how and why things happen, students question one another about what they observe and the conclusions they draw. They question one another about the texts they read. They learn about questioning in this manner, as well as asking testable questions that students can answer by designing, planning, and carrying out an investigation. In some IQWST units, students work together to define a problem, determine how to find a solution, and compare ideas with others in the process of solving the problem.

Driving Question Board

To organize each IQWST unit, the Driving Question is displayed on a Driving Question Board (a bulletin board or large area on a wall). The Driving Question Board (DQB) is a tool used throughout IQWST to focus students' attention, record what they have learned, and show students where they have been and the direction they are going. The DQB serves as a visual reference that remains in place throughout a unit. Lesson plans typically guide the teacher in their use. Although the teacher maintains the DQB, because it functions as a shared space to represent learning, students might also contribute regularly to the display.

Each IQWST lesson addresses a component of the unit's Driving Question, supporting students in making sense of science content and determining which part of a question they can answer and which they still need to investigate. Thus, new lessons are motivated, in part, by what questions still need to be addressed. The visual display supports teachers and students in tracking and organizing ideas along the way.

Each unit invites students to post their own original questions on the DQB to encourage active engagement in a participatory classroom culture. As they think of new questions at any time during the unit, students write those questions on sticky notes and add them to the class DQB. Across a unit, the Driving Question Board will come to include the unit-specified question and subquestions, as well as student questions, drawings, photographs, artifacts, objects, and sample student work. The DQB will serve as a focal reference helpful to all but especially important for students for whom visual representations aid in their learning, such as connecting new ideas to previous understandings. Revisit the DQB with students in each lesson. Refer to it often. Point to artifacts displayed on it as a reminder of previous activities or understandings. Post on it summaries of scientific principles, as well as artifacts students create that relate to specific questions. Any projected image used in IQWST could be printed, laminated, or inserted into a plastic sleeve and displayed on the Driving Question Board. This includes models or data tables developed as a class or any other visual representation of concepts students have studied.

Space on the Driving Question Board may be limited, but it is important that aesthetics and the neatness of the DQB do not outweigh the support provided to students when they can frequently refer to the visual representations as a reminder of activities done and content learned throughout a unit.

Scientific Practice 2: Developing and Using Models

The *Framework* describes the central role of constructing and using models to explain: "Science often involves the construction and use of a wide variety of models and simulations to help develop explanations about natural phenomena. Models make it possible to go beyond observations and imagine a world not yet seen. Models enable predictions . . . to be made in order to test hypothetical explanations." NGSS specifies that models can include "diagrams, physical replicas, mathematical representations, analogies, and computer simulations," all of which contain "approximations and assumptions" that students need to learn to recognize as a given model's limitations. In science, models are used to help people understand, describe, predict, and explain phenomena in the real world.

Scientific modeling consists of several core practices: constructing models, using models to explain or predict, evaluating models, and revising models. IQWST engages students in all of these, supporting learners as they develop models, use models to explain, use models to predict, critique one another's models, and revise models as they learn new information—engaging in modeling as real scientists do. Because modeling is often connected with other aspects of scientific practice, students' experiences with modeling are embedded in the broader context of investigating, understanding, and explaining phenomena. Students create and use models to understand and apply scientific ideas, to illustrate and defend ideas, and to evaluate interpretations.

Engaging Students in Modeling

Students need to understand the purpose of models and modeling in science in order to effectively engage in the practice of developing and using models. Initially, it may be useful to have students think about other models they know, such as models of weather phenomena that scientists use to explain and predict the path of hurricanes, tornadoes, thunderstorms, or snowstorms.

Before Students Develop Models

1. It is helpful to emphasize that the point of developing models is to try to explain the phenomenon just investigated in class. Students' models should demonstrate their best ideas about how to show how and why X happened, so that the model can be used to explain what happened to someone else.

2. Begin to develop criteria for good models, which can be posted in the classroom and used throughout IQWST as students develop their own models and critique one another's models. These ideas should come from class discussion and should be written in students' own language. Important ideas include the following:
    a. Models need to explain. Does the model show *how* and *why* the phenomena happened the way they did? Is there anything in the model that does not need to be here? Are there steps we are leaving out?
    b. Models need to fit the evidence. Does this model fit what was seen about the phenomenon?
    c. Models need to help others understand a phenomenon. Is the model easy to understand? Are there ways to clarify what it shows?
    d. As lessons lead to the need for model revision to account for a new phenomenon, address the idea that models also can be used to predict. Probe students with the following questions: What does our model predict about what will happen in situation X? Was that what actually happened? What does that mean about our model? What do we need to revise based on our new evidence?

Before Students Share Models

It is helpful to give students guidance about how they should listen to each other as they present their models. Eventually students will ask critical questions and make constructive suggestions to each other. Be sure to support that process until they understand this kind of classroom discourse. The following are ideas to address:

1. Different ideas will arise as we try to figure things out. This is our chance to put our heads together and come up with the best model we can come up with, as a group. But we need to agree on what we are looking for. As we listen to each other explain our models, remember what we created these models to try to do. Let's talk about what is important.
2. All scientific models have limitations. Not every aspect of a phenomenon can be explained using a single model. Models often simplify as they illustrate things that are too small, too large, too fast, or too slow to observe without a model as a representation. A static model cannot show movement. No model can sufficiently illustrate the number of molecules involved in a phenomenon nor the time required for others to take place.
3. More than one model can be used to explain the same phenomenon. Scientists judge how good a model is based on how well it helps to explain or predict phenomena—not by how similar it looks to the thing it aims to explain or describe. For example, a good model of gases can be used to explain all the behaviors of gases observed in the real world (e.g., what happens when air is cooled, heated, or compressed), but it will not be used to explain the behavior of solids. Different models have different advantages and disadvantages.

Constructing Models Depends on Scientific Argumentation

The practice of constructing models in IQWST draws critically on another scientific practice, Engaging in Argument from Evidence. In the practice of constructing models in IQWST, argumentation occurs when students defend their proposed models, showing how the model fits evidence and explains the phenomena. Argumentation occurs in classroom discourse when comparing and discussing competing models. IQWST lessons contain support for students to critique one another's models and ultimately to reach consensus, both critical parts of the argumentation practice.

Scientific Practice 3: Planning and Carrying Out Investigations

IQWST is an activity-based, phenomena-rich, investigative curriculum. Students plan investigations that address the Driving Question for each unit and carry out investigations in each lesson. The investigations build understanding of core ideas throughout each unit, always directed at gaining more understanding toward being able to answer the Driving Question. In addition, students' original questions not answered in the unit can be used as a springboard for additional investigation. Some investigations arise out of previous ones in a process of figuring out "what we know as a class" and "what we need to figure out next," typically in learning the how and why of a process. Any such questions can motivate further investigation. Thus, besides those opportunities provided by the curriculum itself, the teacher can require or encourage the planning and carrying out of investigations that extend student learning beyond the performance expectations of a given unit.

Carrying out a multistep procedure is an important science literacy skill; thus teachers might have students plan investigations, write procedures, and share plans and procedures with other groups to read and critique.

Scientific Practice 4: Analyzing and Interpreting Data

IQWST units engage students in observation, data collection and organization, interpretation, and using data to make sense of phenomena they investigate. All lessons regularly use the language of "observation," "data," and "evidence." Teachers are encouraged to ask students to support their ideas with evidence (e.g., Why do you think that? How could that happen? What if . . . ? What evidence do you/we have for that?), requiring students to consider their data carefully. Teachers encourage students to question data provided by others. This creates a situation in which using data as evidence to defend a claim makes sense—students need evidence because they will be questioned about their data in discussion.

Students analyze both qualitative and quantitative data in IQWST. They learn that both are important and while observation with the unaided eye enables them to make some significant claims, instrumentation and scientific tools enable them to be much more precise. Students analyze data they have collected themselves as well as data collected by others (e.g., changes in a population over time, melting points of substances they are unable to investigate in the classroom). Charts and graphs require understanding of independent and dependent variables, and investigations require understanding of what it means to control variables. Throughout the units, IQWST provides students with multiple opportunities to analyze and interpret data through classroom discourse as a whole class, in small groups, in pairs, and independently, providing practice in multiple contexts that reinforce the development of this scientific practice.

Scientific Practice 5: Using Mathematics, Information and Technology, and Computational Thinking

NGSS specifies within this practice ideas such as "using digital tools," for example, "to analyze very large data sets for patterns and trends" and "to test and compare solutions to an engineering design problem." In addition, this practice specifies a need for students to "measure and compare quantitative attributes of different objects and display the data using simple graphs." Therefore, IQWST units include lessons that include probes, sensors, data loggers, and a sensor interface as digital tools that enable quantitative measurement and graphic display in a manner in which real scientists do their work.

IQWST uses the language of *probes*, *sensors*, *data loggers*, and *sensor interface* for illustrative purposes, given rapid changes and advancements in technology and the attempt to use generic terms where possible. IQWST materials show photographs of and reference Pasco brand probes for several activities, as Pasco makes high-quality equipment for middle school use. If your school uses another brand of technology, adjustments may be required in the instructions to students. If your school does not have probeware, and you elect not to purchase such equipment, then more significant adjustment to activities will be necessary, especially where measurements may not be made quantitatively without similar devices. It is recommended, in keeping with the NGSS call for the types of scientific practices considered integral to science education, that probeware be used as recommended in IQWST. More specific guidelines and instructions specific to brands of probeware may be found on the Teacher Portal with updates available to teachers in a timely manner.

Mathematics is used throughout the IQWST program as students take measurements using the tools of science, collect data, plot data on graphs or create data tables, and come to understand and work with dependent and independent variables. Students use scientific probes to calculate in the manner of scientists. Computers are used for simulations of models of phenomena, such as predator/prey relationships, or for observing a phenomenon in slow motion so that it can be more carefully examined.

Scientific Practice 6: Constructing Explanations and Designing Solutions

The *Framework* defines explanations as "accounts that link scientific theory with scientific observations or phenomena" and identifies the related engineering practice of designing solutions, in which students construct and defend solutions to problems that draw on scientific ideas. In IQWST, these two aspects of the practice are combined as constructing, evaluating, and defending evidence-based scientific explanations. The scientific practice of explanation goes beyond asking students to describe what they know about a particular idea. Instead, students develop a chain of reasoning that shows why the phenomenon occurs as it does.

For example, rather than asking students simply to "explain the process of cellular respiration," an IQWST Life Science Unit asks students to "explain why the air a human breathes out contains less oxygen than the air breathed in." Students not only describe the process of respiration but also construct a causal chain that fits the evidence. Drawing on prior ideas from chemistry and physical science, such a chain should specify where glucose goes in the body, what materials can get into and out of cells, and conclude that a chemical reaction requiring both glucose and oxygen must be taking place in cells to convert energy to a form the organism can use.

What Does It Mean to Construct an Explanation?

In the practice of constructing explanations in IQWST, students make claims, use data as evidence to support their claims, and engage in reasoning that draws on scientific principles, or the "what we know" in science, to explain the "how" and "why" of phenomena they investigate in the classroom. Teachers pose questions that push students to think more deeply about what they have observed, read, and experienced, modeling this practice so that students learn to question one another. IQWST lessons support students in critiquing one another's explanations, providing students with opportunities to talk, to write, to discuss, to give and receive feedback, and to revise the explanations they have constructed. Many literacy standards are addressed as students cite evidence from sources; integrate information from observations and from text; write arguments that use a claim, use data as evidence, and use logical reasoning in an explanatory text; and engage in revision focused on writing clearly and coherently for a specific purpose and audience.

Supports are designed around a framework that divides scientific explanations into three smaller, manageable, and teachable components for middle school students: claim, evidence, and reasoning (referred to as the C,E,R framework). IQWST identifies these components in order to support students as they learn to write in a new way.

Claim

A claim is a statement of one's understanding about a phenomenon or about the results of an investigation. The claim is a testable statement about what happened. The claim expresses what the author is trying to help the audience understand and believe.

Claims may be made about data that students have been given or they have gathered themselves. If an investigation has independent and dependent variables, the claim describes the relationship between them.

In practice, teachers have found it useful to teach that a claim must be a complete sentence, cannot begin with "yes" or "no," and is typically the first sentence of an explanation. Although it is not necessary that a claim be the first sentence, experience has shown that freedom to vary the guidelines is best managed *after* the guidelines and their purpose have been learned.

The claim is often the part of an explanation that students find easiest to include and to identify as they critique others' explanations. One of the purposes of focusing on evidence-based scientific explanations is to help students include more than a claim (or "simple" answer to a question) in their writing.

Evidence

The evidence consists of the data used to support the claim. The evidence tells the audience the support the author has collected that makes the claim convincing.

An explanation must contain accurate and sufficient evidence in support of the claim. Evidence makes claims understandable and convincing. While "data" can refer to all the observations that students have collected or analyzed, data become "evidence" when used to support a claim. The evidence for explanations can come from investigations students conduct, from observations they make, or from reports of empirical research others have done. Where possible, explanations incorporate more than one piece of data as evidence.

A goal in IQWST is to help students understand that data must be marshaled as evidence in support of a particular claim. In complex situations, more than one claim might be made about a single data set. It might also be that more data are available than are necessary to support a particular claim. Students must determine which are the appropriate data to use in support of a claim they have made and what are sufficient data to support that claim. The idea that multiple claims might be made using the same data develops across the curriculum as the inquiry activities become more complex, and students' options for research questions (and resulting claims and evidence) become increasingly open ended.

Reasoning

Students learn that the accepted scientific understanding or principles that underlie the explanation must be made explicit in a process IQWST calls reasoning. The reasoning presents the logic that leads from the evidence to the claim and, if possible, connects it with a scientific principle. The reasoning says why the claim makes sense, given what is understood so far about the phenomena. Reasoning ties in the scientific knowledge or theory that justifies the claim and helps determine the appropriate evidence. The reasoning may include a scientific principle that reflects the consensus students have developed so far about the phenomena they are investigating. It may also require a logical chain that shows how the principle and evidence work together to support the claim. For example, the reasoning for the effects of a competitor X on population Y may refer to a series of connected steps that start with the increase in population size of the competing species X, decrease of available food sources needed by both X and Y, and then drop in population size of Y due to lack of food.

The reasoning connects to the general knowledge of the scientific community and a chain of logic to explain how particular data support a claim, given what scientists know about the world. Reasoning is the most difficult aspect of explanation writing for students to understand and is the most difficult aspect for teachers to teach. Reasoning requires relating general scientific principles—what is already known in science—to the specific question being investigated and requires students to make explicit the steps of their thinking.

Scientific Practice 7: Engaging in Argument from Evidence

The *Framework* defines the central role of scientific argumentation in building scientific knowledge as "a process of reasoning that requires a scientist to make a justified claim about the world. In response, other scientists attempt to identify the claim's weaknesses and limitations." In the practice of constructing explanations in IQWST, argumentation occurs when students defend their explanations both in written form, by providing supporting evidence and reasoning, and in classroom discourse, when comparing and discussing competing explanations. IQWST lessons contain support for students to critique one another's explanations and to reach consensus, both critical parts of argumentation. Students learn about criteria for critiquing explanations that also apply to arguments: both must fit the evidence, be logically coherent, fit what is known in science, and include important steps in reasoning.

Argumentation is key in IQWST thus significant attention is paid to evidence-based explanation and argumentation, and students engage in this practice in every IQWST unit.

Scientific Practice 8: Obtaining, Evaluating, and Communicating Information

Student readings provide additional information to support students' in-class investigations. Readings are designed to be integrated into each lesson such that students obtain, evaluate, and communicate information from multiple sources—their own work, others' work, and the science they read about—in all that they do. In addition, opportunities abound for additional research using the Internet, for example, so that students can pursue areas of individual interest that go beyond the performance expectations and grade-level standards. That is, a student who reads about solar sails, described in an IQWST reading as an example of the use of solar power, might wish to learn more about what solar sails are and how they work. Such reading might also trigger interest in alternative forms of energy and their advantages and disadvantages and lead to a written project as situated in the context of the science being studied. This can enable a student to apply his or her understanding to global concerns or to issues in the local community. Such projects, models, and written products that result can interest and motivate students, deepen content understanding, encourage engagement in scientific practices and literacy practices related to science, and provide application and extension opportunities beyond the classroom. In addition, deeper understanding will likely be fostered as the student encounters new ideas in science that fit with the knowledge gleaned from such a project as the core of learning—connecting new understandings with prior knowledge—is strengthened. IQWST does not require research paper types of projects; however, opportunities for teachers to collaborate across content areas such that students might explore science topics as a way to meet literacy learning goals is an option, given that students are likely to encounter many topics they wish to explore further as they investigate phenomenon and read, write, and talk science in every lesson.

INSTRUCTIONAL SUPPORT FOR SCIENTIFIC PRACTICES

The following strategies support students in developing experience with scientific practices.

Use Data to Build Understanding

As designed, earlier IQWST units help students become familiar with observation and data collection and with using data to make sense of phenomena. Teachers are encouraged to ask students to support ideas with evidence (e.g., Why do you think that? How could that happen? What if . . . ? What evidence do you/we have for that?). Teachers allow students to question evidence provided by others. This creates a situation in which using data as evidence to defend a claim makes sense—students need evidence because they will be questioned about it in discussion.

Model the Practice

The teacher uses a think-aloud process to make thinking visible to students. This highlights the underlying aspects of scientific practices, making them explicit as the teacher "talks through" his or her thinking, modeling how good writers, modelers, thinkers, observers, or questioners think as they engage in the practice.

Identify the Audience

All written tasks should be constructed with an audience in mind. This helps students shape their writing, so that the audience can make sense of a written explanation, a model, or a representation of data. In IQWST, students may be asked to think about convincing someone from another class of the validity of the claim in an explanation, to share with someone at home and get feedback, or to explain to an absentee student, someone new the school, or an elementary student.

Motivate the Practice

As teachers incorporate explanation construction and modeling into lessons, they must help students move back and forth between the components of the practice (e.g., claim, evidence, reasoning) and the overall purpose of the practice. Otherwise, focusing on the components becomes formulaic, and students lose sight of the purpose of explanations and modeling in science. To help students see a need for this work, they are placed in situations in which they must engage in argumentation as a way to "convince" someone that their conclusions make sense and can be supported with data.

Generate Criteria

When students are asked to convince one another and to determine whether they are convinced by someone's claim, they need criteria on which to base decisions. Although teachers begin with criteria in mind (described in each unit), they guide students to develop criteria in their own words. The framework can be given to students at the outset; however, students have a deeper understanding of the components and more buy-in when they work cooperatively as a class to generate criteria or the framework for an explanation.

Critique Examples

Students are accustomed to process writing in ELA, but they tend to think that once something is written in other content areas it is finished. Whole-class, teacher-led, and small-group critique of explanations and models helps students see that explanations can be revisited, rethought, and revised. A teacher can create sample explanations for critique purposes. Once students have written explanations, their work can be used anonymously for whole-class critique. Teacher-guided critique, in which the teacher asks probing questions in a discussion, is a useful next step. Once students have practiced in teacher-led sessions, they are ready to critique one another's work. In any critique, strengths and weaknesses should be highlighted and suggestions for improvement offered. It is small-group or paired sharing, in which students compare ideas and justify their use of evidence, that IQWST emphasizes. It is in those comparison and justification activities that deep conceptual understanding takes place, and it is these activities that motivate the use of explanations and models in science.

LITERACY IN THE IQWST CLASSROOM

IQWST supports literacy for diverse learners as students transition from *learning to read and write* in elementary school to *reading and writing to learn* in middle school. Lessons draw on the most recent research in literacy learning, with emphasis on reading comprehension and on the role that reading and writing—in tandem—play in learning. In IQWST, students learn by engaging with the tools, materials, ideas, and principles of science and by thinking, reading, writing, and talking science.

Literacy practices are integrated into every IQWST lesson. The curriculum encourages students to be reflective and critical thinkers, to ask questions of the teacher and each other, to share in small- and whole-group discussion, to read texts that connect science to their everyday lives and prior knowledge, to write responses to embedded questions, to construct models and written explanations and to revise them, to engage in argumentation to defend their ideas and to challenge one another's thinking.

Student books are consumable, functioning as portfolios; the lab activity pages, models and diagrams students draw, readings, and all writing are in one place. Books can be used to teach additional skills by a specialist, support person, or teacher who chooses to teach annotation or highlighting, for example, as students write directly in their books.

Reading in Science

IQWST materials are designed to meet expectations for reading and include strategies to guide teachers in addressing literacy requirements with additional depth or to differentiate for diverse students.

LITERACY GOALS	AS ADDRESSED IN IQWST
Cite specific textual evidence to support analysis of science and technical texts.	Discussion prompts and strategies for teachers and responses to questions embedded in readings ask students to refer to text for evidence.
Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions.	Summarizing or referencing central ideas from text in discussion is often done in the "Reading Follow Up" section that begins most lessons.
Follow precisely a multistep procedure when carrying out an experiment taking measurements or performing technical tasks.	Activity sheets that accompany investigations and homework activities provide extensive practice in reading and following procedures.
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to Grades 6–8 texts and topics.	The language of science is key to science learning. Thus readings address vocabulary in a manner that is context rich, and use of an interactive Word Wall reinforces the reading and the use of science language.

Analyze the structure an author uses to organize a text, including how the major sections contribute to the whole and to an understanding of the topic.	Readings provide opportunities for teacher-led analysis of structure.
Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text.	Readings provide an opportunity for teacher-led analysis of purpose.
Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).	Readings support students in moving back and forth between text and visual information (e.g., "notice the shaded area in the diagram"), and some readings suggest that teachers reinforce this practice when previewing or reviewing readings.
Distinguish among facts, reasoned judgment based on research findings and speculation in a text.	This is best accomplished through suggested projects in which students pursue individual interests or go into more depth studying a topic related to class.
Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic.	Questions such as "How does what you read help you think about yesterday's investigation?" support students in integrating multiple sources of information. Videos and simulations, as well, are interwoven with reading and with hands-on investigations.
RANGE OF READING IN IQWST	
As students transition from learning-to-read to reading-to-learn, IQWST supports them with built-in strategies for students and teachers. IQWST does not provide texts at multiple Lexile levels, based on research that indicates (1) that students who are interested in a topic will choose to read well beyond their test-determined reading level, and (2) that reducing word length and shortening sentences (key strategies for decreasing reading level) can impair comprehension.	Rather than confine students who read below level to reading lesser content, materials suggest strategies for teachers to differentiate instruction so all students have opportunities to use the materials to develop as readers capable of using a range of written materials. Suggestions for students at the top of the grade level reading band encourage independent reading of texts beyond curriculum requirements, so no ceiling suppresses what IQWST students can achieve as readers and critical thinkers.

IQWST readings are integral to students' understanding of science concepts and enable teachers to simultaneously address reading- and writing-related concepts.

Readings

- Extend classroom learning by providing additional examples of principles and concepts encountered in class
- Review in-class activities to help students understand and retain main ideas and to support absent students with content they missed
- Elicit students' prior knowledge and draw on it in engaging ways
- Provide real-world connections that illustrate the value of science outside the classroom
- Use examples with which middle school students are likely to have personal experience or at least be familiar
- Embed questions, to which students write responses, supporting integration of reading and writing in the service of learning, as well as support students' active engagement as readers

Given that the ability to "read and comprehend complex informational texts independently and proficiently" is a lifelong literacy skill, IQWST materials are designed such that readings are intended to be done independently, outside of class time. The few exceptions, in which class time is specifically devoted to addressing some portion of a reading assignment, are clearly indicated in the materials.

Introducing Reading sections in the teacher materials often suggest that the teacher review the Getting Ready section of the student materials as a whole-class, oral activity, thus eliciting whole-class prior knowledge, engaging students in brief discussion, and setting a purpose for the homework reading. Reading setup could take as few as 2 to 3 minutes of class time, or as much as 10, depending on the teacher's purpose, students' abilities, and the nature of the individual activity, but in general, teachers should plan on three to five minutes to introduce the reading.

The Student Edition

Annotated versions of the student pages—in the Teacher Resource Book—provide the teacher with likely student responses or expected responses (including correct answers, where appropriate) as well as ideas for using those responses as formative or summative assessments.

Driving Question Notes and Scientific Principles Pages

The first few pages of every student edition are provided as note-taking space in which students can record both their own individual ideas that connect with the Driving Question, and those big ideas generated by the class. Students should record their own original questions and can add information about those as they progress through the unit. Scientific principles are big ideas that the entire class "arrives at" by the end of many lessons and that students record for ongoing reference. The teacher materials often suggest ideas to be recorded on these pages, but they can be used to record any information the teacher or students deem appropriate. Tracking of scientific principles is a way to ensure that the class articulates "what we know so far" as students progress through the unit; it has common language to draw on when constructing explanations or arguments that draw on these big ideas.

Activity Sheets

IQWST students experience phenomena in a problem-based, investigative context, typically guided by activity sheets for each lesson. These pages support students as they plan and carry out investigations, follow procedures, make predictions and compare them with what happened, organize and analyze data, and make sense of science. Activity sheets often include an opportunity for students to explain the *how* or *why* of a phenomenon, deepening students' understanding as they engage in scientific practices.

Having a student read the "What will we do?" section aloud is one strategy to provide students with an overview of activities in which they are about to engage. Read through the procedure with students, demonstrate it, highlight key components, or summarize briefly so that students conceptualize the big picture of what they are going to do. For example, tell students "You are going to observe two materials separately, and then observe them again after you put them together. It is important that you describe your observations in the table on your activity sheet. Then, you will write some questions about what you observed." Such review frames the activity for all students but is especially important for students who need to hear and not just read the procedure or who need to understand the big picture before making sense of the individual steps.

Homework

Some take-home assignments are designed as extension activities, typically requiring students to apply what they have learned to new contexts. These assignments reinforce in-class activities, providing independent practice focused on key ideas in each unit.

Using IQWST Readings Effectively

The Teacher Edition provides two primary ways of supporting students as readers in science by taking a brief amount of time to introduce the readings and consistently following up on readings in class discussion, as bell work at the beginning of class, or in a quiz-type format.

Introducing Reading

The best way to introduce readings is for the teacher to take the first few minutes of class time to generate interest. Materials typically include an Introducing Reading section with ideas. While spending a few minutes can have tremendous payoff for students, sometimes the teacher will be pressed to do something quick. Most important is that something is done to introduce the reading in order to engage interest, elicit prior knowledge, and set a purpose for reading.

Reading Follow Up

It is important to follow up the readings or other homework. Use the embedded assessments for grades or points or use them to generate follow-up discussion to begin a class period. Students held accountable for reading either through assessments or through in-class questions that require having read the materials in order to participate in discussion are more likely to read as homework. As they enter class, a simple way to do this is to have on the board an opening question that draws on what they read.

Writing in Science

LITERACY GOALS	AS ADDRESSED IN IQWST
Write arguments focused on discipline-specific content. (a) Introduce claims, distinguish from opposing claims, and organize reasons and evidence logically. (b) Support claims with logical reasoning and relevant, accurate data, and evidence. (c) Clarify relationships among claims, counterclaims, reasons, and evidence. (d) Maintain a formal style. (e) Provide a concluding statement that supports the argument.	One pervasive opportunity in IQWST is for students to construct evidence-based explanations of phenomena they investigate and to analyze and give feedback on the written explanations of their peers. In some units, this is taken a step further into argumentation, with written and oral defense of arguments: a key scientific practice supported when the unit content is conducive to argumentation. Reading and discussing writing can help students deepen their own understanding, hone their critical thinking skills, and support consensus-building or argumentation skills in a group.
Write informative/explanatory texts, including scientific procedures/experiments. (a) Introduce the topic clearly and organize ideas, concepts, and information as appropriate to achieving purpose. (b) Develop the topic with relevant facts, details, or other information. (c) Clarify the relationships among ideas and concepts. (d) Use precise language and domain-specific vocabulary to explain the topic. (e) Maintain a formal style and objective tone. (f) Provide a concluding statement that supports the explanation presented.	In addition to the information in the previous box, students write explanations in response to questions embedded in their reading materials and on activity sheets to conclude and make sense of investigations. Additional opportunities to write explanatory texts are often provided in the Differentiation Opportunities sections that precede each lesson.
Narrative skills—for example, write precise enough descriptions of step-by-step procedures they use in investigations that others can replicate them and (possibly) reach the same results.	Students write step-by-step procedures when they design investigations, engaging in an important scientific practice.
Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.	All explanations and arguments in IQWST are designed for a specific purpose and audience, and many other writing tasks define a purpose and audience so that students learn to write for different purposes.
With some guidance and support from peers and adults, students develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on how well purpose and audience have been addressed.	Process writing, as learned in ELA, is used throughout IQWST as students compose evidence-based scientific explanations and arguments, share them with peers, give and receive feedback, and revise.

Use technology, including the Internet, to produce and publish writing and present the relationships between information and ideas clearly and efficiently.	Opportunities to use the Internet to search for information and to inform writing are provided as Differentiation Opportunities to enable students to pursue curriculum-related topics in which they are keenly interested or for the teacher to assign topics to advanced students so that they might "go beyond" the curriculum's learning goals.
Conduct short research projects to answer a question (including a self-generation question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration.	Self-generated questions are at the core of IQWST, generated in the initial lesson in each unit, and then questions are continually encouraged throughout. Students write their questions on sticky notes, post them on a Driving Question Board, and are advised (or can be required) to investigate them independently.
Gather relevant information from multiple print and digital sources, using search terms effectively; assess the credibility and accuracy of each source; and quote or paraphrase the data and conclusions of others while avoiding plagiarism and following a standard format for citation.	In order to engage in the previously mentioned activity, students draw on multiple resources, including in-class activities and readings and Internet searches for other resources.
Draw evidence from informational texts to support analysis, reflection, and research.	Students draw on multiple resources including in-class activities and readings and Internet searches for other resources.

Summarizing is another valuable way to use writing. Summarizing requires determining and restating main ideas and findings. To support students in summarizing key ideas, provide practice for them to verbalize their thinking before writing or time to write about their ideas before sharing orally. For instance, before writing a summary of a reading, students could be asked the following: *How would you summarize this reading for students who were absent yesterday? What did they miss that they need to know?* After discussing, students will be better prepared to write summaries. Writing before sharing orally enables students to think and to process what they have learned before they are called upon to share ideas in class. These and other strategies support students as readers, writers, speakers, and listeners in the context of the science classroom.

In addition to the multiple opportunities provided for students to write to learn in IQWST lessons, activity sheets, readings, and home assignments, teachers can provide additional opportunities to meet the needs of individual students, many of which are suggested in the Differentiation Opportunities section that precedes each lesson.

Speaking and Listening

LITERACY GOALS	AS ADDRESSED IN IQWST
Engage effectively in a range of collaborative discussions (one-on-one, in-group, and teacher-led) with diverse partners . . . building on others' ideas and expressing their own clearly, (a) come to discussions prepared, having read required material, (b) follow rules for collegial discussions, (c) pose and respond to questions with elaboration and detail . . . connect the ideas of several speakers and respond to others' questions and comments with relevant evidence, observations, and ideas; and (d) acknowledge new information expressed by others and, when warranted, qualify, justify, or modify their own views in light of the evidence presented.	These behaviors are addressed in daily discussion, often as a follow-up to reading, to make sense of science during and after investigations and as a precursor to writing. Students given opportunities to talk about their ideas and those of others; to use talk as a way to think more deeply; and to critique claims, evidence, and reasoning orally are then better positioned to be able to write convincingly about their ideas. In addition, talking through ideas in this manner enables students to make sense of reading they have done or can set up reading as students read purposefully to determine whether their ideas were right, wrong, or somewhere in between.
Interpret and analyze information, main ideas, and supporting details presented in diverse media and formats (e.g., visually, quantitatively, orally) and explain how the ideas clarify a topic, text, or issue.	As students engage with phenomena during investigations, their work requires interpreting and analyzing information that is visual/observational, verbal as expressed in both oral and written texts, and both qualitative and quantitative, requiring students to synthesize information from multiple sources.
Delineate a speaker's argument and specific claims, evaluating the soundness of the reasoning and the relevance and sufficiency of the evidence.	Activities throughout IQWST that call for explanation or argumentation also call for students to share and to critique one another's ideas.
Present claims and findings, sequencing ideas logically and emphasizing salient points in a focused, coherent manner; use appropriate eye contact, adequate volume, and clear pronunciation.	Activities throughout IQWST that call for explanation or argumentation, as well as modeling, also call for students to present their ideas to a partner, a small group, or to the whole class.
Include multimedia components and visual displays in presentations to clarify claims and findings and emphasize salient points.	Visual displays, especially models that accompany explanations and arguments, are constructed and shared in every IQWST unit.
Adapt speech to a variety of contexts and tasks, demonstrating command of formal English when indicated or appropriate.	The primary manner of speaking and listening in IQWST is presenting ideas for comparison with others' ideas and both giving and receiving oral feedback.

Classroom Culture

Establishing a culture in which students actively participate in "talking science" is at the core of IQWST, but it is challenging for both teachers and students. By the time students have reached the middle grades, they know a great deal about what it means to "do school." They raise their hands, do so only when they think they have the right answer, and respond to teacher-posed questions rather than to peers' ideas. In an IQWST classroom, students ask questions that arise out of individual interests or concepts about which they are confused. They ask questions of other students, as well as the teacher. Science discussions promote active engagement in science learning such that everybody expresses their understanding and learns from each other. The goal is for students to develop as thinkers and problem solvers through participating in thoughtful talk about core content.

Sharing ideas openly, asking questions of one another, defending one's ideas, and not having right answers challenges many students, as well. Students who are successful when reading and answering questions may not be comfortable discussing and exploring alternative ways to explore concepts. Students may be uncomfortable participating in discussions if they are unsure of the correct answer or may be uncomfortable with the idea that multiple responses may be considered correct at a given time in the process of learning. Students who are successful doing activities and discussing their reasoning may struggle when they are required to write about their ideas. Students who have looked to the teacher for answers and guidance may find it unusual that they need to question another student or provide rationale for their responses.

Establishing a classroom culture wherein students feel comfortable sharing and discussing with each other and feel confident about participating actively begins on the first day of class. Since IQWST may introduce a new manner of discussion for students, the teacher will need to model sharing, listening, and learning with students by demonstrating the value of contributions, not just correct answers. The primary goal of oral discourse is for students to articulate their own understanding and to listen and respond to each other. This goal is assisted when the following occurs:

- All students are provided opportunities to participate.
- All students are encouraged to participate.
- Students are encouraged to think together, rather than only speak, if they think they have the correct answer.
- Students see the value in wrong answers for figuring things out.
- Students are provided opportunities to write their responses before sharing aloud.
- Students use information in readings as a springboard for discussion.
- Students listen carefully to others and respond to others' ideas.

Small-group discussions are an integral part of the inquiry process in IQWST. They provide the best opportunity for students to learn from each other and interact with their peers as well as with the teacher. It is important that all students have an opportunity to participate, express their ideas, listen to one another, and respect others' ideas. Developing a classroom culture in which this is the norm may take time, especially if this is not what students are accustomed to in other classroom settings.

Teacher Supports

IQWST lessons support teachers by providing scaffolding to help facilitate conversation. Teacher supports include a list of possible questions or prompts a teacher may use or adapt, as needed, possible student responses, information about what student responses might suggest about their understanding, and ideas about how to address those ideas. The lessons support the teacher in creating a culture of science discourse by providing question stems such as these:

- What can you add to make this idea clearer?
- How does this idea compare to the idea of the previous speaker?
- What can you add to expand on what was just said?
- How can you summarize our conclusions?

Three Types of Discussion

IQWST lessons identify discussions by type to assist teachers in recognizing the structure of the discussion and conducting the discussion according to the guidelines for each.

In IQWST, brainstorming is any discussion with the purpose of generating and sharing ideas without evaluating their validity. Prompts provided for all brainstorming discussions are suggestions meant to encourage students to express their ideas. It may be useful to record ideas on the board, on a computer, or on a transparency so that students can see what has been said and can build on others' ideas. A photograph of notes recorded on the board, a printout, or a transparency can be attached to the Driving Question Board as a reminder of the activity.

1. Discussion: Brainstorming
   Purpose: To articulate and share ideas without evaluating their validity.
   - All ideas are accepted in brainstorming.
   - Ideas are captured and recorded as they are generated.
   - Brainstorming prompts include the following:
     - o What have you observed or experienced?
     - o What do you think about when you hear the word . . . ?
     - o What do you know about . . . ?
     - o Who has a different way of thinking about this topic?
   - Follow-up can include, as appropriate, such questions as the following: Where does that idea come from? How do you know? Where have you heard/seen/experienced that before?
2. Discussion: Synthesizing
   Purpose: To put ideas together or assemble them from multiple activities into a coherent whole.
   - Discussions may include making connections to personal experiences, to the Driving Question, and to other lessons or content areas.
   - Synthesizing prompts include the following ones:
     - o How does this connect to . . . ?

- o How does this support the Driving Question?
- o How does this help us think about the activity we did yesterday?
- o What do we know about this topic so far?

In IQWST, the purpose of a Pressing for Understanding discussion is to get students to think more deeply and to make sense of their experiences. Some questions can lead to a simple answer, others to a deeper, more thoughtful answer. Learning through inquiry encourages students to think more deeply but only if their thinking is scaffolded until they learn to think in terms of how and why, to make connections, to analyze, and to synthesize. Probing questions such as *Why do you say that?, What makes you think that?,* and *How do you think that works?* invite students to think more deeply and, over time, establish a culture in which doing so is the norm in science class.

3. Discussion: Pressing for Understanding

   Purpose: To figure things out or make sense of readings or activities while going deeper and beyond surface answers.

   - Discussions may involve respectful challenge, debate, or arguments in which students justify their ideas.
   - When pressed, students may revise their previous ideas as they learn new information that shows the limitations of their previous understandings.
   - Pressing for Understanding prompts include the following:
     - o How do you know? What evidence supports that idea?
     - o Why does our old model not work to explain this new phenomenon?
     - o How could we figure this out?
     - o How does . . . compare to . . . ?
     - o What new questions do you have?

THE LANGUAGE OF SCIENCE: VOCABULARY

New Meanings, Familiar Words

Science as a discipline is known for its challenging vocabulary; thus IQWST lessons contain supports to help students develop deeper understanding of science concepts, including how, when, and why particular language is used. Students are engaged in thinking about the language of science in multiple ways.

IQWST takes a research-based, contextual approach to science language, stressing the repeated, ongoing, pervasive use of new words in oral and written discourse, acknowledging that language and conceptual understanding develop hand-in-hand. Science words are taught as they are needed. Typically, after a concept has been encountered, it is then given a label (the vocabulary word). A primary support for students occurs when teachers use science vocabulary frequently and appropriately and guide students to do so as well.

One of the hallmarks of successful readers is their ability to understand word meanings as they occur in varied contexts. When the teacher uses science vocabulary in context and calls attention to similarities and distinctions between words, all students are supported in building their science vocabularies. Students' everyday understanding can help or hinder their understanding of the uses of many words in science. Words like *absorb* and *reflect* have everyday uses that are consistent with their meanings in science, so linking the everyday to the scientific is likely to be helpful. However, words like *volume* and *mass* or words that name scientific practices such as *modeling* or *explanation,* have everyday meanings that may not help students understand the meaning in science. In those cases, making differences explicit supports students in learning multiple uses of words, including specific uses in science.

Simple routines used before students read new text can help students recognize and use science language as they read, write, and discuss their developing understandings.

Prereading

Before asking students to read independently, the teacher can identify words that will be difficult for the class. Words the teacher anticipates will be difficult can be rehearsed by displaying them (on the board or on a Word Wall), pronouncing them, and providing a snapshot definitions aimed only to help students recognize the words when they encounter them in the context of written text. This scaffolding helps students move words from listening and speaking vocabulary to their reading and writing vocabulary.

Building Vocabulary

Many science words have common prefixes, suffixes, or root words. Building a list of words with similar word parts allows students to see, define, and make connections between words such as *biology* and *ecology*, especially when connected to biosphere, ecosystem, eco-friendly, biochemical, and biography, among others.

For teachers required to do more intense vocabulary study at the middle school level, strategies should support students in developing deeper understanding of science concepts, rather than simply memorizing textbook-style definitions. Although writing vocabulary words in sentences is common school practice, it has not been shown to promote science vocabulary learning. Thus time is better spent engaged in tasks that use science vocabulary: constructing oral and written explanations and arguments, composing brief summaries, and answering questions that require both critical thinking and the use of appropriate vocabulary.

Interactive Word Wall

Keeping a space in the classroom to post new science language, as new words are encountered, provides students with multiple exposures to new words and allows them to refer to the Word Wall when communicating ideas, formulating questions, or writing (and learning to spell science vocabulary). Having words posted allows the teacher to gesture to the Word Wall during discussion to support students in using science language in their talk. Words written on sentence strips can easily be moved to increase opportunities for connecting words in various ways, grouping them or creating concept maps. Word Walls may be enhanced by short definitions or by visual representations, as well. Students with artistic ability or who like to draw, or who learn by the act of creating representations may create visuals to post on the Word Wall along with new words. Most important is that the classroom is language rich, providing students with ongoing exposure to discipline-specific vocabulary, which supports them as readers, writers, and critical thinkers in science.

ASSESSMENTS

Embedded/Formative Assessments

Formative assessment opportunities are embedded within IQWST lessons. They occur during discussions, activities, and readings and can be used to gauge students' understandings and developing science ideas in the moment. Formative assessments used regularly during the learning process enable the teacher to determine whether concepts need to be revisited, whether an optional activity would be beneficial for student learning, whether discussion should be extended or guided differently in order to support student learning, or whether some or all students would benefit from additional support. Formative assessments also enable teachers to provide explicit feedback to students on their ideas, so students can know in what ways they are on track toward meeting learning goals. Formative assessments also enable teachers to differentiate instruction in response to students' current understandings. Questions embedded in readings and as suggested prompts for discussion include possible student responses and, where appropriate, correct answers. When using embedded assessments to gauge students' understanding, analyze responses by listening for students'

- the ability to connect previous ideas with new content;
- the ability to summarize ideas accurately;
- current content understanding, as it will lead to meeting learning goals; and
- developing use of appropriate science language.

Summative Assessments

Many of the embedded assessments, while designed for formative use, may be assigned points or letter grades. Any written response in the student books may be seen as a summative opportunity. An option is to invite students to submit their one "best response" to questions in a lesson or their best evidence-based explanation or other revised response for a grade. This practice acknowledges that motivation, interest, and understanding vary from day to day and recognizes that assessing one's best work helps students be more aware of their own performance and what constitutes "good work" in science. IQWST also provides a bank of questions, available electronically, and in Word format, that teachers may draw from to customize quizzes and tests. Questions may be used as they are or adapted to best match instruction or to meet students' needs (i.e., differentiation).

SAFETY PRACTICES

Laboratory investigations excite students about the practice of science and lead to reflective discussions about investigation design and the real work of scientists. With investigations comes the need to teach laboratory safety and practice safety precautions with middle school students who may be new to lab experiences.

Science teachers are expected to take all possible actions to avoid accidents in the laboratory setting and to monitor labs for hazardous chemicals or flammable materials. This includes standard safety practices that include housekeeping to keep the laboratory areas clear of clutter and prohibiting unsupervised access to areas where electricity, chemicals, or heat sources are used.

Teachers should provide information about, and practice, laboratory evacuation drills. Gas and electricity should be shut off during any drills or whenever the class is leaving the lab. All exits must be kept free from obstructions, and no materials should be stored outside of the lab storage room. Safety rules should be posted in the room and reviewed with students prior to lab work. If the teacher, school, or district has specific science rules, those should be posted.

IQWST lessons contain specific safety information at the start of each lesson and throughout the lessons for easy reference for teacher and student. MSDS sheets should be consulted for appropriate use of all chemicals.

Science Lab Rules

There are many science rules to ensure safety in the laboratory. IQWST lessons have specific science cautions through each lesson to guide teachers and students, but middle school students, because of their inexperience with science labs, may need to be aware of certain safety procedures that include the following:

1. Clothing and Hair—Loose or baggy clothing, dangling jewelry, and long hair are safety hazards in the laboratory.
2. Cold and Heat Protection—Cold or hot materials should only be touched with hands protected by items such as safety tongs, safety mittens, or rubber gloves. In some instances, only the teacher should handle materials at extreme temperatures (e.g., dry ice).
3. Food—No eating, drinking, or use of cosmetics should occur during lab time. Even familiar substances used in activities (e.g., marshmallows for molecules) should not be consumed, as they may be contaminated in the lab setting.
4. Glass Caution—Glass should be used cautiously, and students should report any chipped, cracked, or scratched glassware should such occur during a lab activity.
5. Housekeeping—Work areas should be kept clean at all times, with backpacks, books, purses, and jackets placed away from lab tables.
6. Washup—Hands should be washed with soap and water before and after laboratory work. Students should not touch their faces or hair with either bare or gloved hands that have handled lab materials.

7. Safety Equipment—Personal protective equipment such as goggles, gloves, and aprons should be used as appropriate for the activity.
8. Allergies—All allergies should be noted for students and a plan put in place if peanuts, peanut oil, latex, or other known allergenic items are used in the lab. For example, although gloves and goggles provided in IQWST materials are latex-free, some units use balloons, which students with latex allergies should not handle.
9. Sniffing—When directed to "sniff" in the lab, students should be taught to follow the teacher's directions for "wafting" odor to the nose.

These rules are general and should always be followed in a lab situation. IQWST provides a letter to parents that discusses science safety rules. If a school or district has another science letter, and/or additional safety rules, teachers should use the district letter and follow all school or district guidelines for safety in the science lab. For additional safety information, consult the NSTA safety portal at http://www.nsta.org/portals/safety.aspx.

SAFETY LETTER

Dear Students, Parents, and Guardians:

Middle school science consists of engaging topics for students to investigate in a lab setting. However, any science activity may have potential safety issues if not conducted properly. Safety in the science classroom is an important part of the scientific process. To ensure a safe learning environment, a list of rules has been developed and discussed with all students because science rules must be followed at all times. Additional safety instructions will be given for each activity. Please discuss the safety rules with your child and return the bottom of this letter.

No science student will be allowed to participate in science activities until the student and a parent or guardian have acknowledged their understanding of these safety rules by signing this document.

Science Safety Rules

1. Conduct yourself in a responsible manner at all times in the science room.
2. Follow instructions carefully. Ask questions if you do not understand the instructions.
3. Use equipment (e.g., scissors and sharp items) only as directed by the teacher.
4. Perform only approved experiments.
5. Never eat, drink, chew gum, or taste anything in the science lab.
6. Keep hands away from face, eyes, and mouth while using science materials. Wash your hands with soap and water after the activity.
7. Wear safety goggles when instructed. Never remove safety goggles during an experiment. There are no exceptions to this rule!
8. Clean all work areas and equipment, and dispose properly of any waste materials.
9. Report any accident (spill, breakage, and so on), injury, or broken equipment to the teacher immediately.
10. If you have allergies, it is important that your teacher knows about them and that you avoid handling materials that could cause problems. For example, if you are allergic to latex, you can participate in activities that use balloons, but you should not be the one to handle the balloons.

SAFETY AGREEMENT

Dear Students, Parents, and Guardians:

We are providing the Science Safety Rules to keep you informed of the school's effort to create and maintain a safe science classroom/laboratory environment for all students.

Your signature on this letter indicates that you have read the Science Safety Rules, have reviewed them with your child, and are aware of the measures taken to ensure the safety of your son/daughter in the science classroom.

Parent/Guardian Signature: ______________________________

Student Signature: ______________________________

Date: ______________________________

Important question – Does your child have any health issues or allergies? If yes, please list them here.

Unit Overview

Can I Believe My Eyes?

Can I Believe My Eyes? is an eight-week, project-based unit. In order to contextualize the content, the opening activity provides a common experience in which students view two optical illusions and begin to ask questions about what they see and why, which leads to discussion about the role of light in seeing. Why is it important for students to learn about light? Although many people do not realize it, the scientific principles that explain the behavior of light are the same principles that govern much of the behavior of cellular phones, computers, MRI scanners, microwave ovens, nuclear power plants, televisions, satellite communication, GPS, and many other systems. In fact, nearly all of the major scientific discoveries and major technological advances made in the last 100 years are based, directly or indirectly, on principles underlying the behavior of light. It is impossible to make sense scientifically of the world in which we live without understanding how light propagates and how it interacts with matter. Along with the particle nature of matter, energy conservation, and evolution, light's behavior is truly one of the big ideas in science.

DRIVING QUESTION

The Driving Question for the unit is Can I Believe My Eyes? The target science ideas and inquiry processes are instrumental to understanding the initial activity and answering the Driving Question. Students complete several investigations, each time cycling back to the anchoring activity. Each cycle helps them delve into the science content to gain a deeper understanding of how light moves through space, what happens when it meets objects and materials, how our eyes detect light, how colors of light can be perceived to be different than what they really are, and finally, nonvisible light. Throughout the unit, a model of light and sight is developed, applied to explain new phenomena, critiqued, modified, and reapplied.

Four learning sets comprise the instructional sequence.

LEARNING SET 1

The first learning set, comprised of five lessons, addresses major learning goals to help students understand (1) how light moves through space, (2) the conditions that need to be met to be able to see something, and (3) a basic model of the relationship between light and vision. Initially, students experience two optical illusions and generate questions about the anchoring activity, about the Driving Question, and about light and vision in general. These questions are organized into a Driving Question Board that guides the remainder of the unit. Almost every lesson begins and ends by referring to the Driving Question Board. In Lesson 2, students discuss what they think is needed to see something and then use shoeboxes constructed to enable them to investigate sight in two different scenarios. The next lesson has students build physical models that represent the role light plays in vision and to decide upon and draw a consensus model. This lesson includes an introduction to the value of models. In Lesson 4, after a brief discussion about the eye, students use light sensors/probes around the room to help them understand the eye as a passive sensor of light. Lesson 5 provides an opportunity to apply their model of light to the phenomenon of shadows.

LEARNING SET 2

Learning Set 2 is comprised of three lessons about the interaction of light and matter. In Lesson 6, students are introduced to reflection and the distinction between reflection and scattering. After the Law of Reflection has been established in a qualitative manner, students investigate light's reflection from coarse and smooth surfaces. Lesson 7 revisits the consensus light model students developed and demonstrates a limitation of the model: It does not lead to correct predictions regarding phenomena involving transparent materials. After establishing the need to understand how light can pass through objects, students use the light sensors to investigate transmission through different materials. They compare what they perceive with their eyes to what they measure with the sensors to reinforce the value of measurement tools. Lesson 8 deals with absorption, the final way light can interact with objects and materials. Students experience phenomena that illustrate that light can make things happen when it is absorbed. Learning Set 2 ends by revising the model of light to account for reflection, transmission, and absorption.

LEARNING SET 3

Learning Set 3 focuses on color and how objects reflect and transmit some colors and absorb others; how eyes perceive mixtures of different colors of light as new colors; and how to determine the color composition of light. In Lesson 9, students learn that the colors their eyes see may not necessarily be the actual colors of light entering them. Using computers, students mix red, green, and blue light to create different perceived colors. Students attempt to create black light, only to realize that there is no black light; black is the color we see when no light reaches our eyes. The lesson ends with a brief lecture on how the eye and a digital camera detect colors and the parallels between them. In Lesson 10, students learn how to analyze light to determine the colors of which it is composed. They investigate which colors are absorbed and transmitted by different-colored filters and different colored opaque objects. The lesson ends with students explaining why different objects appear to be differently colored (even though the same light illuminates them) and applying this idea to the anchoring activity. Lesson 11 is a summary lesson with the anchoring activity revisited and a complete explanation constructed for the phenomenon.

LEARNING SET 4

In the final learning set, the physical difference between different colors of light is investigated. The students learn about waves and wavelength. They are introduced to the idea that there are "colors" of light that are not visible—infrared and ultraviolet light. Phenomena involving visible and nonvisible light are investigated using light sensors. The unit ends by returning to the Driving Question and discussing the limitations of our eyes and the value of using instrumentation in investigating physical phenomena.

UNIT CALENDAR

Unit Driving Question – Can I Believe My Eyes?

Learning Set 1: How Does Light Allow Me to See?	
2 Class Periods	**Lesson 1 – Anchoring Activity and Driving Question Board**
	Activity 1.1: Anchoring Activity – Strange Images
	Reading 1.1: Look at This!
	Activity 1.2: Driving Question Board
2 Class Periods	**Lesson 2 – What Do We Need to See an Object?**
	Activity 2.1: Probing Ideas: Seeing Objects around the Room
	Activity 2.2: Determining the Conditions for Sight – The Light Box
	Reading 2.2: Picture This!
2 Class Periods	**Lesson 3 – Constructing Models of How People See**
	Activity 3.1: Preparing to Develop Models
	Reading 3.1: Modeling
	Activity 3.2: Building the Consensus Model
	Reading 3.2: Faster than a Speeding Bullet
1 Class Period	**Lesson 4 – The Eye as a Light Sensor**
	Activity 4.1: How the Eye Works – Overview
	Homework 4.1: Exploring Shadows
	Reading 4.1: Eyes in the Animal Kingdom
1 Class Period	**Lesson 5 – How Are Shadows Created?**
	Activity 5.1: Introducing Shadows
	Homework 5.1: A Midnight Crime
	Activity 5.2: Connecting Shadows to the Light Model
	Reading 5.2: All Shadows Are Not the Same
	Reading 5.3: Stars and the Solar System
Learning Set 2: What Happens When Light Reaches an Object?	
3 Class Periods	**Lesson 6 – Scattering and Reflection of Light**
	Activity 6.1: Reflection
	Activity 6.2: Investigating Scattering and Reflection

	Homework 6.2: Scattering and Reflection – Part 1
	Activity 6.3: Explaining Scattering, Reflection, and Images
	Homework 6.3: Scattering and Reflection – Part 2
	Reading 6.3: Polishing Objects
	Reading 6.4: Moon Phases
2 Class Periods	**Lesson 7 – Transmission of Light**
	Warm-Up Activity
	Activity 7.1: Evaluating the Light Model
	Activity 7.2: Measuring Light Transmission
	Homework 7.2: Transmission of Light – Part 1
	Activity 7.3: Revising the Light Model
	Homework 7.3: Transmission of Light – Part 2
	Reading 7.3: Using Light in Optical Fibers
2 Class Periods	**Lesson 8 – Absorption of Light**
	Activity 8.1: Light Makes Things Happen
	Activity 8.2: Investigating Heating by Light
	Reading 8.2: Solar Power Plants
	Homework 8.2: Absorption of Light
	Activity 8.3: Keeping Track of Light
	Activity 8.4: Revisiting Phenomena Caused by Light
	Homework 8.4: Absorption of Light
	Reading 8.4: Solar Energy
Learning Set 3: How Can Light Have Different Colors?	
3 Class Periods	**Lesson 9 – What Is the Opposite of White Light?**
	Activity 9.1: Mixing Colors of Light with Projectors
	Activity 9.2: Mixing Colors of Light on Computers
	Activity 9.3: How Color Sensors Work
	Reading 9.3: Making Color Photographs
3 Class Periods	**Lesson 10 – How Do Objects Change the Color of Light?**
	Activity 10.1: Analyzing Color Composition
	Reading 10.1: Rainbows
	Activity 10.2: Revisiting the Consensus Model

	Reading 10.2: Lunar and Solar Eclipses
	Reading 10.3: Diffraction
2–3 Class Periods	**Lesson 11 – Back to the Anchoring Activity**
	Activity 11.1: Revisiting Learning Sets 1–3
	Activity 11.2: Explaining How We See Objects, Including Optical Illusions
	Reading 11.2: Solar Eclipses
Learning Set 4: Is There Light I Cannot See?	
2 Class Periods	**Lesson 12 – Infrared Light and the Wave Model**
	Activity 12.1: What Is Leaving a Remote Control?
	Reading 12.1: Infrared Light
	Homework 12.1: Is the Remote Emitting Light?
	Activity 12.2: Introducing the Wave Model
2 Class Periods	**Lesson 13 – Ultraviolet Light and Nonvisible Light Imagery**
	Activity 13.1: Investigating UV Light
	Homework 13.1: UV Light and UV/IR Imagery
	Reading 13.1: Nonvisible Light
	Activity 13.2: How Would the World Look if People Could See UV and IR Light?
	Homework 13.2: UV Light and UV/IR Imagery

PS1 SCIENTIFIC PRINCIPLES

1. An object can be seen if four conditions are met: there is an object, an eye, a source of light, and a direct path between the object and the eye.
2. Light must enter the eye or sensor to be seen or detected.
3. The brighter an object appears, the more light that reaches the eye or detector from it.
4. Light travels in straight lines.
5. Light continues traveling until it reaches an object that scatters or absorbs it.
6. A shadow is formed behind an object that blocks the path of light.
7. A shadow is seen by detecting that less light reaches the eyes from it than from the area surrounding it.
8. Scattering occurs when light bounces off an object in all directions. This occurs when the surface of the object is rough and unpolished.
9. Reflection occurs when light bounces off an object only in a certain direction. This occurs when the surface of the object is smooth and polished.
10. A reflection of one object is seen in a second object only if the second object reflects light, not if it scatters it.
11. Some objects are transparent and let light pass through them.
12. When light reaches an object, it is scattered (or reflected), transmitted, absorbed, or some combination of these.
13. Light can make things happen when it is absorbed.
14. When different colored lights are mixed, they appear as a new color, brighter than the original colors.
15. White light is a mixture of all colors of light—it is the brightest color. Black is the color associated with the absence of light.
16. Filters color light by absorbing certain colors and transmitting the rest.
17. Colored objects scatter only certain colors of light and absorb the rest.
18. There are many different wavelengths of light. Most of these cannot be seen.
19. Different wavelengths of visible light appear to us as different colors.

Lesson 1

Anchoring Activity and Driving Question Board

PREPARATION

Teacher Background Knowledge

The "Strange" Images

Students should not be expected to understand how optical illusions work. Each learning set contributes crucial pieces of information needed to explain the phenomenon. The full explanation of both images involves the brain and the way it interprets signal that reach it from our eyes. While students should be able to understand by the end of this unit how information about the images reaches our eyes and how our eyes translate this information into signals that are sent to the brain, they will not be able to understand the way the brain gives meaning to these signals. Students who realize that they understand only part of the story may wish to continue learning about the brain so as to understand the second part as well. This may be a method by which you challenge some students at the end of this unit.

Exploring Phenomena

Throughout IQWST, students will encounter use of the word *phenomenon* or its plural form, *phenomena*. Phenomenon is a word used in science (and thus in IQWST) for anything interesting that occurs and for which data can be collected. Students commonly think the term refers to events that are outstanding, strange, or exceptional. Discuss the different ways words are used in science and in everyday language. Over and over again, students will investigate phenomena such as why an object falls to the floor when they let go of it, or why they breathe harder when they exercise, or why the sun makes their skin feel warmer. These are everyday phenomena—nothing exceptional—but are events they can observe and that scientists ask questions about and examine to try to figure out the how and why behind the phenomena.

The Driving Question Board (DQB)

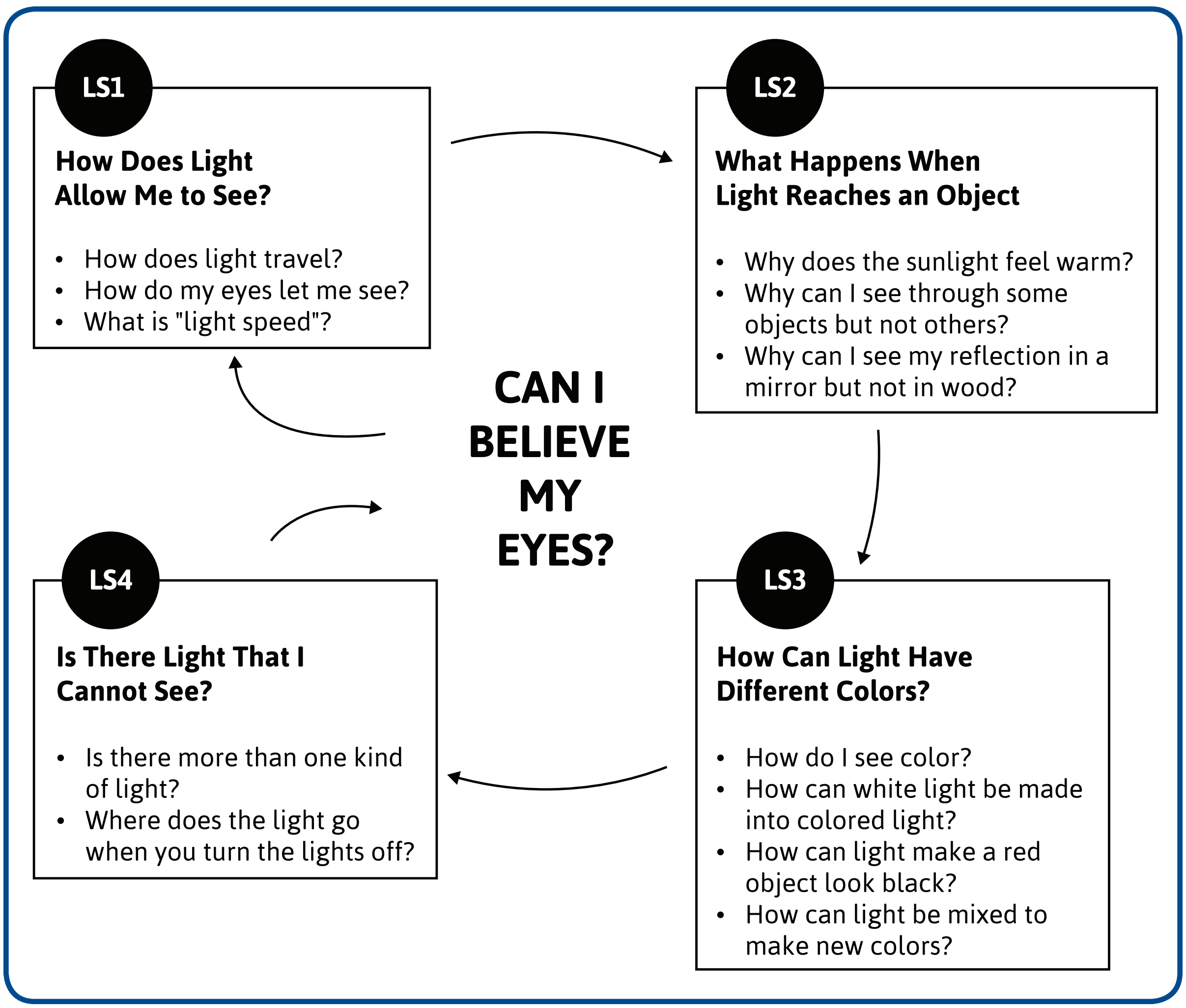
The DQB is a tool used throughout IQWST to focus students' attention, record what they have learned, and show students where they have been and the direction they are going. It gives them a hook on which to hang their ideas, and it does so visually, so that the entire class has a shared, public space for sense making. The DQB also gives the teacher a reference point to use throughout the unit. Use the Driving Question Board you create for Lesson 1 in each lesson. Post on it artifacts your students create that relate to specific questions, and aim to answer as many questions as possible by the end of the unit. It is important to refer to the DQB often in order make connections among activities and to support students' conceptual understanding. There are no rules about what should be posted on the DQB beyond the Driving Question, the unit subquestions, and periodic guidance in the unit. But you may post any artifact you think it would be useful to maintain as a visual reference for your students. (See IQWST Overview for more about using the Driving Question Board.)

Setup

Preparing the Driving Question Board (DQB)

Before students come into class, the Driving Question Board should be posted. It should be large enough that it can be seen and referred to easily during the unit. You will refer to students' questions throughout the unit, and they will add new questions as they are raised. The subquestions for each learning set should be the same as the sample DQB (shown here). However, the questions within each subcategory should be those asked by students in your class. Condense, summarize, combine, or group students' questions if you wish. Most important is that questions are in students' language and that students recognize their questions as posted and acknowledged. You might spend a moment with questions that cannot be answered with empirical evidence to reshape those questions now or later in the unit.

At the start of a new learning set, you might select students' questions related to the topic that organizes it and arrange them under that question. For example, at the start of Lesson 2, say something like "Many of your questions were related to the nature of light and how it allows us to see. I have grouped those questions together on the DQB under a general question:



How does light allow me to see? We will now begin with some investigations that will provide evidence to help answer that set of questions."

This diagram illustrates a possible DQB setup with learning set categories named. However, the questions within each category should be the questions posed by your students written on sticky notes and posted initially as well as throughout the unit.

⚠ Safety Guidelines

Refer to IQWST Overview.

Differentiation Opportunities

Each of the following suggestions can enable teachers to address particular aspects of the Common Core related to Reading and Writing Standards for Literacy in Science. In addition, Speaking and Listening Standards are readily addressed any time students are called upon to make presentations or to discuss ideas with their peers.

Sharing Optical Illusions

1. Allowing students to share other optical illusions they find in books or on the Internet is a way to engage all students in the material, as optical illusions are a puzzle to everyone! Take photos or attach to the DQB (or a separate space in the classroom) others that students bring in. Having a stake in figuring out what makes an optical illusion "work" that a student finds on his or her own gives that student increased motivation for learning the ideas in this unit. You may then choose to assign some students the task of looking for an optical illusion that they find particularly puzzling and bringing it in to share. Later in the unit, explaining an optical illusion that they found could serve as an assessment opportunity.

Optical Illusions and the Brain

2. Students may search in other sources for optical illusions and use those to stimulate investigation of how a particular one works. They may apply what they read in Reading 1.1 to explain, or they may do additional research into what happens in the brain. This unit focuses on the role of light in how people see as the context for learning about light's interaction with matter and other core ideas in physical science; it does not focus on how the brain works. Investigating more on that topic might be of special interest to some students.

Students' Original Questions

3. Some of the questions that students will raise in Activity 1.2 will not fit into any of the subquestion categories. These could be assigned to students as an ongoing project that they complete by the end of the unit or by the end of a learning set using various resources. Consider assigning this project to groups, to students who will benefit from

the challenge of the additional work associated with this task, or to students who have a particular interest in a particular question. “Obtaining, Evaluating, and Communicating Information” is one of the eight Science and Engineering Practices required to meet NGSS. Thus Internet searches that require students to consult multiple sources of information provide a way to address this practice in the context of learning the Disciplinary Core Ideas of this unit. At the same time, the ELA Common Core Standards require students to “conduct short research projects to answer a question (including a self-generated question) drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration.” Thus other standards may also be met through such exploration.

Lesson 1

Anchoring Activity and Driving Question Board

TEACHING THE LESSON

Performance Expectation

Students will make observations and ask questions to guide the investigation of core ideas related to light and its interaction with materials so that humans can see objects.

Overview

Activity 1.1
Observe two "strange" images and discuss observations.

Activity 1.2
Generate questions (that will form the DQB) about light, seeing, or the strange images.

Building Coherence

This lesson introduces students to an intriguing phenomenon that serves as a common, anchoring experience for the unit: optical illusions. Students generate original questions that will be organized into a Driving Question Board (DQB) to be used throughout the unit.

Timeframe

2 Class Periods

Materials – Activity 1.1

For the Teacher
- (1) projector connected to a computer*
- PI: Moving Circles
- PI: Checkerboard
- Driving Question Board*

For Each Group
- sticky notes*

For Each Student
- Activity Sheet 1.1
- Reading 1.1

*This item is not included in the kit.

Activity 1.1 – Anchoring Activity – Strange Images

Review the importance in science of making close observations using the senses (sight, hearing, touch, taste, and smell) and recording observations so that they can be referred to later.

Display PI: Moving Circles. Students record observations on Activity Sheet 1.1. Ask: "What do you see?" *(Students describe observations.)* "Do the circles seem to be turning?" *(Not all students will think the circles are turning. Have them focus on any one circle. When they look at it, it does not seem to be turning, but others do.)* "Can you control what happens? Does this mean the circles are actually turning?"

Show PI: Checkerboard. Ask: "Are squares A and B the same shade of gray, or is one darker than the other?" *(Students will say that A is darker than B.)* Continue to the next images until the entire checkerboard is covered except for these two squares. End again by asking which square is darker.

Students record observations and respond to the Making Sense questions. Ask: "How do you think the turning circles image works? Why do you think one square appears darker than the other even though they are the same color?" *(It is important for students to articulate their ideas about light and how it relates to sight.)*

- When scientists (and students) record their observations, what they record is called data.
- Recording observations enables scientists (and students) to refer back to previous experiments.
- It is important to record observations promptly and accurately, so they can be studied to draw conclusions.
- If the same data are observed and observations are noted in the same way, scientists (and students) can compare their data.

Science is about asking questions about how the world works and gathering evidence to help understand and explain the answers to those questions. Science relies on data collected by observing phenomena. Students made observations, and by doing so and comparing data with one another, they recognized a pattern: They cannot always believe their eyes. The goal of this unit is to gather evidence to help answer the Driving Question: Can I Believe My Eyes? Ask: "How would we answer this question based on the activity we just did?" *(Conclude: We cannot always believe our eyes.)*

Describing the ways that IQWST activities represent the kind of work that scientists do will help students learn what science is and how it is done. Now that two unusual images have been observed, students can generate questions as a class and work to investigate and answer as many of them as possible over the next few weeks. The idea of asking questions, making observations, and organizing and interpreting data to find patterns that can be used to explain things in the world will occur over and over again throughout IQWST.

Have students record on their activity sheets questions they have that relate to the images, to light, or to seeing.

Introducing Reading 1.1 – Look at This!

Reading 1.1 introduces students to differences between optical illusions and physical illusions. Ask: "Who has seen an optical illusion? What are some examples of optical illusions you have seen?" Project some of the optical illusions in Reading 1.1 (or others you find), and ask students how these compare to the two images they saw in class. Ask: "Are the checkerboard image and the spinning circles optical illusions? Explain your ideas."

Students should always articulate reasons for their responses—why they say yes or no—but it is not important that they have a correct answer. The purpose is to realize that we draw on prior knowledge and experiences for our ideas—and for learning—so articulating those ideas is important.

Activity 1.2 – Driving Question Board

Reading Follow Up

Now that students have had a chance to read about optical illusions, ask: "Were the checkerboard image and the spinning circles image optical illusions?" Encourage students to describe what in the reading led them to change their minds or helped them support what they were already thinking. *(It is important that students determine that these two images are optical illusions that trick their brains. Ask any student who thinks they are not optical illusions to point to a part of the reading that supports their idea.)*

These two images point to several things students could ask questions about. One of the important things they may have observed in the activity was the light source. Ask: "What are some light sources?" *(Light sources are the sun, overhead lights, lamps, flashlights, candles, fire, headlights, projector, TV, phone, or computer screens.)* List students' ideas on the board, so that they can refer back to them.

As you move through the following discussion and students generate questions, instruct students to write each question that arises on an individual sticky note.

Discussion – Brainstorming

Purpose

Generate original questions with which to populate the DQB and to motivate students' interest.

Suggested Prompts

- The two images raise questions about how we see. What are some factors that affect vision and the way we see objects? *(Students might mention time of day, the need for glasses, curved or funhouse mirrors, looking through water at something, colorblindness, cataracts, telescopes, binoculars, microscopes, getting eye drops at the eye doctor, wearing sunglasses, and tinted windows.)*

- We saw the images on the screen because light from the projector shone on the screen. What are some results of light when it hits different materials or objects? *(Light illuminates or makes some things visible, it bounces off shiny objects such as metal or glass, it warms up dark objects, and it passes through some objects, such as sunlight through window.)*
- What questions do you have about the effects light has when hits different materials or objects? *(For example, why do colors [e.g., fabric, paper] fade in the sun? How do sunglasses block out certain rays? How do mirrors and glass reflect images? How can you see through a window, but if you focus differently, you can also see your reflection at the same time? Why do plants need sun, but then if there is too much sun they die? Why does the sun make people sweat? Why does metal get so hot in the sun? Why do some objects melt in the sun, but other things do not? Does it hurt for animals to drink hot water when it has been out in the sun? Why do clothes on the clothesline dry faster when it is sunny outside? Why does the sun make my whole house hot?)*
- You observed an interesting pattern related to the colors of the light and the colors of the image with the spinning circles. What are some different situations where you might see colored light and its effects? *(Some situations are traffic lights, black lights, light through colored windows or glass, or holiday lights.)*
- What questions do you have about eyes, vision, and how we see? *(For example, does it hurt [damage] your eyes to look at the sun? Why do my cat's eyes look creepy at night? Why are some people colorblind? Would a colorblind person see the images the same way the rest of us did? How can you still see light even with your eyes closed? Does a blind person know when it is brighter or darker?)*

Call on a student to post a question. If students have an identical question, they should add theirs to it to acknowledge shared ownership. If a student has a question relating to a previous student's question, the student should raise a hand, read the question, and indicate how it is related. Next, the student should post the question attached to the edge of the other question. Make as many connections as possible until everyone is able to post at least one question.

An important part of learning science together is making connections to other people's ideas. Asking questions, listening carefully to each other, and making connections may be new to students. This practice of saying things like "My idea is like hers because . . ." or "I thought about that but in a different way . . ." is a discourse practice to encourage and practice. You might make a poster of possible language options to help students begin to develop this practice. This also sets a tone of scientific discourse and classroom culture—the teacher does not repeat everyone's question, but students listen and respond to one another. This posting process takes awhile, but an important exercise is listening and making connections and establishing that shared learning, shared knowledge, and shared ideas are important in science. (See IQWST Overview, DQB section, for ideas.)

You could repeat this process three times, each time focusing on a different unit subquestion: how light interacts with objects and materials, how light can have different colors, and whether there is light that cannot be seen. Or you could open generally and build the board by having students suggest whether their question connects with the previous sharer's question or if it does but maybe goes in the next section. There is no right or wrong way to do this. Questions that do not fit any of the subquestions can go in a *Parking Lot*.

Wrapping Up the Lesson

Throughout the unit, students will gather evidence to help them answer many of the questions and to answer the Driving Question.

At the beginning of the student book are blank pages for Driving Question Notes, where students will record ideas that may help them answer the Driving Question or their own questions. Students should record the Driving Question and perhaps one to three questions they found most interesting today. At the end of activities or lessons throughout the unit, you will provide time to add additional information to these pages, either as you (or the curriculum notes) direct or based on students' own ideas. Scientific Principles are a particular category of science ideas that you will learn through your investigations and agree are "ideas we have learned" or "ideas that are important in science," and you will all list the same Scientific Principles throughout the unit. The Scientific Principles should also be posted in the class—as you go and in students' own language—either as part of the DQB or in a separate place in the room, as space allows.

LESSON 2

What Do We Need to See an Object?

PREPARATION

Teacher Background Knowledge

Fair Test

Students might think of the hidden-objects Activity 2.1 as a game like I Spy, or a contest in which they want to answer "yes" more times than their peers. Therefore, you might begin with a discussion of *fair* test in a science experiment. In this experiment, in order to make everyone's test close to the same, the class must agree on what it means to look for an object from their seats. It is possible for students to look in all directions by turning their bodies, leaning, among other things, but turning to look 360° defeats the purpose of the activity. Stress that students should turn their heads but not their bodies and that the purpose is not to be able to see everything but to figure out what they can and cannot see. **No one will be able to see everything**. Also caution students not to talk to one another, nor to reveal to their peers where something is when they have spotted it in the room. This activity is engaging, and the period of revealing its results is fascinating for students and sets up the conditions for seeing that will be used throughout the unit. Thus talking about fair test sets a tone that even as we investigate and enjoy what we are doing, we will follow the practices of science as closely as we can.

Discussion in IQWST

In each lesson, IQWST identifies different discussion types and states their purposes to support teachers in asking the most useful type of questions and knowing when and how to press students' responses. For example, in a brainstorming discussion, whose purpose is to elicit students' prior knowledge so that it can be built upon in the lesson, the only questions typically needed are those meant to clarify what a student is thinking ("Say a little more about that") or to probe reasoning behind a response ("What makes you say that?"). In a summarizing discussion, questions that probe what we know now and how we know it ("What evidence do we have for that?") are more useful. The IQWST Overview has several sections devoted to establishing norms for classroom discourse and to facilitating thoughtful discussion in whole-class or small-group settings. The Overview also offers generic questions that can be asked as written or can be tailored to particular discussions.

Conditions for Seeing

The four conditions may not be the only ones needed to see an object. For example, one might correctly argue that the object's size or the distance between the object and the eye impact whether people can see it or not. The four conditions used in the model in this unit are intended as a starting point, as they are necessary to address standards related to how light (waves) are reflected, absorbed, or transmitted through various materials. The four conditions are not intended to be memorized as a comprehensive list of the only possible conditions.

Wave-Particle Properties of Light

In the activities in this lesson, students might comment on the fact that the diameter of the spot on the wall gets bigger or smaller as a flashlight is moved closer to or farther from it. There is a relationship between the size of the spot and the distance from the wall because light actually travels outward from a source as a wave front. Think of a wave front as the surface of a balloon. As you blow into the balloon, its diameter expands, similar to the size of the circle of light on the wall. Light has the properties of both a wave and a particle. It is not important for students to explore the wave-particle dual properties of light. For the purpose of this unit, the path of light is treated as a straight line. This is called the ray model of light. The spot gets bigger or smaller as the flashlight gets nearer or farther from the wall because light spreads outward from a source. This will be further explored in Lesson 5 when students investigate shadows.

Analyzing Patterns

Data analysis is an important link between observations and claims. Much of the data analysis is qualitative in this unit. For example, it is a qualitative pattern that no student can see the object in the light box when the light flap was closed. It is important for students to learn that observations can be analyzed, and once patterns are found in those observations, the patterns can be used as evidence to support scientific ideas.

Common Student Ideas

The Role of Light and the Eye

Students might not recognize light as something that travels from a source to an object. They often do not recognize that light from an object needs to enter the eye for the object to be seen. Instead, they often think that the eye actively observes an object. As you read students' responses on their activity sheets, there is no need to challenge their responses in the first activity. The following activities in this lesson are designed to provide evidence that light travels in straight lines and must enter the eye.

Some students typically believe that the light needed to see an object is coming from the eye rather than to the eye. Cartoon characters and superheroes that shoot beams from their eyes contribute to this common idea. If students express this, ask them to close the flap of the light box back up and look for the object. Ask: "If the light is coming from your eye, why are you not able to see the object when the light box is completely closed?" With support, they should realize that the light must be coming from the outside of the light box rather than from their eye.

Light as an Entity

Students typically think of light as an entity that fills a space rather than something that moves between points. Sample probing questions aim to help students recognize that light is moving from one area (outside the light box) to another (into the light box) and from the object in the light box to their eyes.

Setup

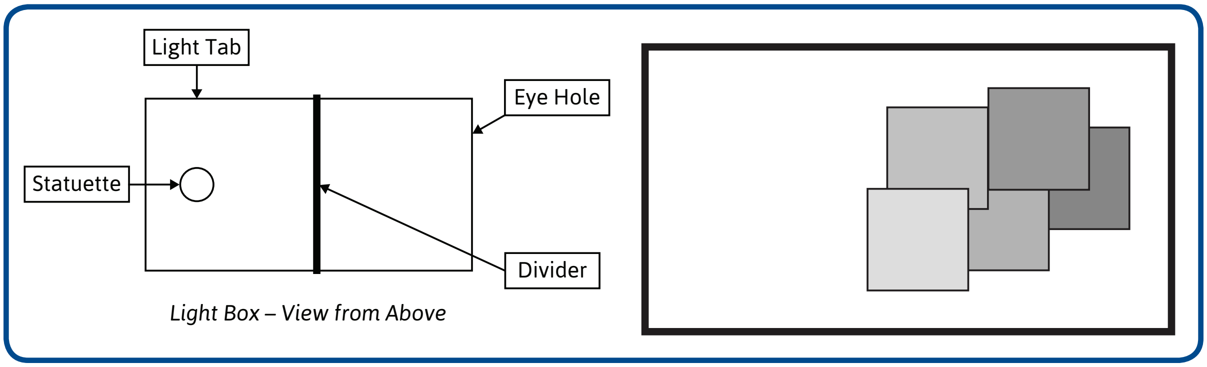
Activity 2.1

Before class, place six to eight easily identifiable objects around the room. Objects should be visible to some students but not others (with some students' view of the object being blocked). Place a stuffed animal, for example, on the floor next to a desk or table so that only students sitting to that side of the table can see it; students on the other side will not be able to do so. Place one object so that no students can see it. Place another so that all students can see it. The placement of objects so that most can be seen by only some students is necessary to establish key concepts about a straight, unblocked path for light to travel from an object to someone's eyes.

Activity 2.2

Prepare light boxes from shoeboxes with lids. If available, shoeboxes with hinged lids work well because the lids are less likely to fall off as students pass the light boxes around. On the short end of the shoebox, cut a small round hole (about the size of a penny) near the bottom. Label it eyehole. When the light box is held up to the eye, it should look completely dark inside. If there are places where light is coming in, cover them with construction paper or tape to prevent light from entering. On the long side of the box, away from the side where you cut the round hole, cut a square, 1.5" tab that can be folded up to create an opening and then folded down again to seal the opening. This will allow light to enter the box (when needed) by folding up the tab. After cutting, tape a piece of construction paper or cardboard over the tab to prevent light from entering the box (around the slits) when the tab is closed. Label this light tab.

The statuette should be small enough to fit standing up in the light box with the lid completely closed. All the light boxes should contain identical statuettes. They should be asymmetrical, so students cannot guess what the entire statuette looks like if they are able to view only one side of it. Statuettes should also be relatively easy for students to draw. Using glue or tape, fix the statuette in each light box in the same place and the same orientation, so that the light boxes are as close as possible to identical.



Light Box – View from Above

Prepare dividers—pieces of cardboard that fit into the light box—but do not put them in the light boxes until the appropriate point in the lesson. Each divider should have a 2in square hole cut in a different place so that the light boxes will provide different views of the statuette. Dividers can be taped to the sides of the boxes so that they remain upright and in position. See to the drawings and photograph images for reference. The time to add the dividers to the boxes will be specified in the lesson.

Safety Guidelines

Refer to IQWST Overview.

Differentiation Opportunities

Refer to IQWST Overview.

Lesson 2

What Do We Need to See an Object?

TEACHING THE LESSON

Performance Expectation

Students will use, analyze, and interpret data from observations to explain that an object can or cannot be seen depending on whether light from the object enters the eye.

Overview

Activity 2.1
Compare observations to determine patterns in what is needed for people to see an object.

Activity 2.2
Investigate the ability to see an object, and use observations to establish four conditions that need to be met in order to see an object.

Building Coherence

This lesson provides evidence for four conditions (the existence of light, an object, an eye, and a straight path for light to travel between the object and the eye) necessary to answer questions on the DQB related to the question: How Does Light Allow Me to See?

Timeframe

2 Class Periods

Materials – Activity 2.1

For the Teacher
- (1) projector*
- PI: What Affects Sight?
- PI: What Hinders Sight?
- PI: What Can You See?
- (6–8) hidden objects*

For Each Student
- Activity Sheet 2.1

*This item is not included in the kit.

Introducing the Lesson

If you did any regrouping of students' questions on the DQB, explain that and indicate that students will now be addressing the question: How Does Light Allow Me to See?

Have students close their eyes and think about how they would know there is such a thing as light if they were unable to see. *(People are aware of light primarily because they can see, so it makes sense to begin investigating light by investigating how people see and what role light plays in seeing.)*

Discussion – Brainstorming

Purpose

Elicit initial ideas about how people see.

Suggested Prompts

- What do people need to be able to see an object? *(list ideas)*
- What could happen that would keep someone from seeing? *(too dark, something blocks their vision, eyes are closed, blindness)*

Show PI: What Affects Sight? and have students respond to Question #1 on Activity Sheet 2.1. Encourage students not worry if they are unsure, stating that sharing their initial ideas is important to all learning. When students finish, show PI: What Hinders Sight? and have them write responses.

Activity 2.1 – Probing Ideas: Seeing Objects around the Room

Place objects as indicated in Setup. Instruct students that they cannot move in their seats other than turning their heads. The goal is not for everyone to be able to see everything, and in fact, some objects are placed so that they are supposed to be visible only to some students. When they finish, they will be looking for patterns in what people can and cannot see.

Name objects one at a time. Students write the name of the object in the table on Activity Sheet 2.1 and then put a mark in the box for each object they can see.

Show PI: What Can You See? Review the list of objects one at a time. As each is named, students raise hands if they could see the object. Students should look at raised hands and begin to think about what students who could see an object have in common and how they differ from people who could not see it. If time is short and you hurry through some items on the list, take the most time to discuss objects that could be seen by some students but not all. Once students have had a chance to observe who could see the various objects, have them talk in small groups. Then have the whole group discuss patterns and what conclusions they can draw about what is necessary to see an object.

Discussion – Synthesizing

Purpose

Compare data, note patterns, and establish what is needed in order to see an object.

Suggested Prompts

- What patterns did you notice that are related to who could and could not see different objects?
    - o What did the position of objects you could see have in common?
    - o What did the position of objects you could not see have in common?
    - o What did all the people who could see a particular object have in common?
    - o What did all the people who could not see an object have in common?
- What factors affect whether you can see an object or not?

Some students can see an object, while others cannot because of their position in the room. Students may begin to discuss the idea of light's path, which will be more fully developed in Activity 2.2. Students will use Activity Sheet 2.1 again at the end of the next activity.

Materials – Activity 2.2

For the Teacher

- (1) string or ruler
- (1) flashlight
- PI: What Affects Sight?
- PI: What Hinders Sight?

For Each Group

- completed light box* (described in Setup)

For Each Student

- Activity Sheet 2.1
- Activity Sheet 2.2
- Reading 2.2

*This item is not included in the kit.

Activity 2.2 – Determining the Conditions for Sight – The Light Box

In the remainder of this lesson, you will be working with students to generate a list of conditions that need to be met to see an object: an eye, an object, light, and a straight, unblocked path between the object and eye.

Hold a statuette like the one in the light boxes in your hand so students can see it. Ask: "Based on the evidence you have collected so far, what is needed in order to see this object?" *(List ideas students suggest using evidence from Activity 2.1.)*

Provide groups with one shoebox per group. Explain that students are not to look in or open the box until you instruct them to do so. Explain that each group has a light box with an object inside. Students should take turns looking through the eyepiece and record on Activity Sheet 2.2 what they see. *(They will not be able to see the object because it is completely dark inside the light boxes.)* After students have had time to record observations, have them leave the lid closed but open the flap on the side of the light box. They should look again through the eyepiece and describe what they see.

Discussion – Making Sense

Purpose

Compare observations and interpret data to determine what is needed to see *(If light, an eye, an object, or straight, unblocked path between the eye and the object are not already on the list of things needed to be able to see, add them as they come up in discussion.)*

Suggested Prompts

- How was what you observed different when the flap was open compared to when it was closed? *(Students could see and describe the object with the flap open but could not see it with the flap closed.)*
- Why were your observations different? *(With the flap closed, light could not get into the light box, but with it open, light could enter allowing them to see.)*
- Where is the light coming from? *(It comes from outside the box, the lights in the room, or the sun.)*
- Where does that light end up? *(It ends up in the box, on the object, or in the eyes.)*
- How does the light get there? *(This question may cause some confusion. Answers will vary.)*

The Light Box with Divider

Add a divider to each light box. Each group should get a different divider; each should block a different portion of the object. Have students look through the eyepiece again and sketch on their activity sheets what they see. Make sure they sketch only what they see, not what they think might be there. When students finish their sketches, they should compare results with another group without looking inside one another's boxes.

Suggested Prompts

- How was the sketch you made similar or different to the one made by the other group? *(The sketches show different parts of the object. They may also say that it is the same object. Encourage them to describe what they see, rather than making inferences about what they cannot see.)*
- Why are the sketches different? *(They cannot see around the divider, or it blocks their view of part of the object.)*
- Why can you not see around a divider?

If no one raises the idea, suggest that because light travels in straight lines, they see different parts of the object when the divider is in different positions. Ask students for other examples of where a straight, unblocked path might be needed. Answers might include shooting a gun, playing billiards, or playing a video game. The aim is to further establish that there must be an unblocked, straight path along which light moves to the eye. After answers have been shared, add "unblocked, straight path between the object and eye" to the list on the board.

To further develop the idea of light traveling in straight lines, guide students through the following exercise by modeling the procedure. Have students hold their left hands about four inches in front of their left eyes. Have them close their right eye and keep their left eye open. Instruct them to move their right index finger across from the right until they appear to be just behind their left hands. Have students open their right eye and close their left eye.

- What happened when you switched back and forth between eyes? *(It is important that students be able to describe their finger disappearing and reappearing.)*

With a string or straight edge and a volunteer, show students how the path from the finger to the eye is blocked in one situation and not blocked in the other. The path between the left eye and finger was blocked, so they could not see the finger, while the path between the right eye and the finger was not, so they could see it. An object can only be seen if the path between that object and the eye is not blocked by something else, so that light can travel between the two.

The Path

Dim the lights. Turn on a flashlight and shine it on the wall where students can see it. Ask the following questions to prompt discussion.

- Where is the light coming from?
- Where is the light going?
- How did it get there?

Begin moving the flashlight around slowly. Continue the questioning.

- Why is the light on the wall moving the same way the flashlight is moved?
- Why does moving the flashlight cause the light spot to move?

Turn the flashlight off, point it in a new direction, and ask: "Where will the light appear on the wall when the flashlight is turned on? Explain your idea." Turn on the flashlight to show that the students' prediction was (roughly) correct. It is important that students recognize the pattern—that the spot moves when the flashlight moves because light always moves in a straight line away from the flashlight.

At this point, the list on the board should mention all four conditions that need to be met in order to see an object. Ask students the following: Imagine you look out the door right now, just as a friend walks by and waves to you. Using the conditions we have just listed, how would you explain how you can see your friend? What evidence did you discover, or what activity did you do, to support the claim that an eye, an object, light, and an unblocked path are all necessary to be able to see?

- Insert the following on the Scientific Principles list: Four conditions need to be met for an object to be seen—an object, an eye, a source of light, and a direct, unblocked path between the object and the eye (using the students' own language).
- In the last two activities, students used data as evidence to support their ideas. Science is about investigating and making claims that can be supported. This support comes in the form of data derived from observations or measurements and can be used as evidence.
- When students get an idea they want others to concur, encourage them to look for data that will support the idea. For example, if they think an unblocked path is important to being able to see an object, they might talk about the data collected in the last activity that showed only people with nothing blocking their line of sight to an object could see it. That would be evidence.

Return to Activity Sheet 2.1 and PI: What Affects Sight? In groups, give students a couple of minutes to identify the reasons that the girl can see the tree. Next, have students use the list on the board to think again about this situation. How are the four conditions present or not present? When finished, choose one group to report their ideas. Ask for other groups to comment on any differences they had. *(The tree could be seen because the four conditions for seeing were all met: eyes [on the girl], an object to see [the tree], light [from the sun], and a straight path for the light [from the tree to the girl].)*

Use PI: What Hinders Sight? Have students use the list to think again about this situation. What conditions might help explain why the girl cannot see the car? Have a group report their ideas and encourage other groups to comment. Encourage students to use terminology from the list. *(There is no unblocked path in this situation.)*

✓ At the beginning of Lesson 2, students likely explained that the girl could not see the car because of her position or because the wall was blocking her view. These answers imply that the eye plays an active role in seeing objects. In IQWST, it is important that students learn to articulate their ideas. At this point, students should explain how the girl sees the wall using the scientific idea that because the light's path from the wall to her eye is unblocked, she can see the wall, but because the light's path from the car to her eye is blocked by the wall, she cannot see the car.

Wrapping Up the Lesson

Discussion – Synthesizing

Purpose

Address the Driving Question or other questions on the DQB.

Suggested Prompts

- What questions from the DQB are we now able to answer?
- What questions can we add to this part of the DQB?
- How does what we learned help us think about the Driving Question: Can I Believe My Eyes? *(If students struggle to respond to this question, use the following focused prompts.)*
  - o Imagine you are in a room with no light in it . . . would you believe what your eyes are telling you—that there is nothing in the room? Explain your ideas.
  - o Imagine that you are facing a brick wall . . . would you believe what your eyes are telling you—that there is nothing but a wall in front of you? Explain your ideas.

Have students add relevant information and additional questions to the Driving Question Notes near the beginning of the student book.

Introducing Reading 2.2 – Picture This!

The reading explores how it is that people see something that is not really there, such as an image on a television. TV, film images, and art are used as examples to explore how it is that pixilation produces images and enable students to compare this process with how people see objects. To introduce the reading, the Getting Ready section can be done in class, as will often be the case across IQWST. This type of reading extends classroom learning, helping students see the relevance of science to life outside of science class. Sometimes the contexts are unfamiliar (e.g., solar-powered cars) and are used to pique students' interest. IQWST aims to have students understand that science learning is not just for science class—that science applies to events in their everyday experiences and to new opportunities for them in the future.

Lesson 3

Constructing Models of How People See

PREPARATION

Teacher Background Knowledge

The Scientific Practice of Developing and Using Models

A scientific model can be thought of as a representation (or set of rules or relationships) that scientists use to illustrate, explain, and predict phenomena. Scientific models are not all-inclusive; rather, they highlight key components, characteristics of those components, and relationships among the components. (See IQWST Overview for a discussion of models and modeling, as "Using and Developing Models" is one of eight Science and Engineering Practices required by the Next Generation Science Standards.) Models are useful in every scientific discipline. The modeling practices in which students engage in this unit will be revisited and built upon in IQWST units that follow.

Consensus Models

The consensus model of seeing will be revised throughout this unit. At this point, students do not need to think about revision because they have not completed experiments that suggest the need for a revised model. However, some students may anticipate the need to revise the model if they have mentioned transparent objects. In Learning Set 2, students will revise their ideas about the way light interacts with transparent, translucent, and opaque objects. In Learning Set 3, they will revise their idea of the nature of light to include color. In Learning Set 4, the model will be revised to include forms of nonvisible light.

This consensus model, like any model, has certain features, strengths, and weaknesses.

- Features—The consensus model represents the nature of light and how people see. It specifically represents light as rays that propagate outward from the light source, interact with objects and materials (by bouncing off of them), and is detected by the eyes (as it enters and is absorbed by the eyes). There are multiple arrows on each ray to imply that light travels continuously from the light source.
- Strengths—It helps predict and explain simple examples of seeing (ones that involve a single light source, a single object that scatters light, and an eye with a direct path between the object and the eye).
- Weaknesses—The consensus model is two-dimensional and not three-dimensional (like the physical world). It is not a dynamic representation, though scientists know that light travels over time through space. It is a simplified model that includes only one object, one light source, and an eye. It does not explain light as a wave phenomenon. It does not explain how light interacts with objects or the properties of color. Light is actually emitted in all directions from each point of the light source.

The Ray Representation of Light

Straight lines with arrows are used to represent the path of light, with arrows showing the direction in which light is traveling and multiple arrows showing that light travels continuously from the light source in all directions. This way of thinking about light is useful because it describes the path light travels from one place to another and why there are places light cannot reach (e.g., when light is blocked by a tree or building). This representation also has two limitations that do not need to be discussed explicitly with the students:

- Light travels in all directions in three-dimensional space. Two-dimensional diagrams can only depict rays on the plane of the paper.
- Light is emitted in all directions from each point of a light source. Rays are shown to emanate in all directions from the light source in general, not from each point in the light source.

Research suggests that when diagrams include both real and symbolized entities, students may misinterpret what is real and what is symbolized. In addition, research suggests that students may not be familiar with conventions that allow one to show invisible entities in a diagram; these conventions need to be taught explicitly. Without explicit discussion of the status of rays, students may interpret them as visible and/or material entities.

Students may also interpret the rays in diagrams as a person's vision. It is important to be clear that the arrows are a convention that will be used for representing light rays. If a student draws light rays from the eye to an object, ask the student what the arrow represents. If they respond that it represents a person's vision, ask them if the rays exist even when the person's eyes are closed.

Common Student Ideas

Models

Students often think that a model needs to look like the thing it represents. They are more likely to resonate with the model car example than their drawings. Help students understand that there are many types of models (diagrams, equations, and computer simulations, in addition to physical or material models) and that they all serve to help make sense of scientific ideas and to communicate those ideas. Emphasize that models can help people understand, explain, and predict and that their drawings can help them do that.

How Light Travels

A common student conception is that light does not continuously move but instead comes from a source and either fills a room or sits on the walls and ceiling of a room. Students do not think of light as continuously moving away from a source and bouncing off the walls into their eyes. Reading 3.1 introduces students to the speed of light, which explains why light appears to fill a room instantly when a light is turned on. Refer students back to the light box activity and ask them to explain where the light came from when the light flap was opened on the light box. Then ask them what happens to the light inside the light box when they close the flap again. The concept to stress is that the light moves all the time, but it can only move into the light box when its path is not blocked.

Setup

Activity 3.1

Cut two sheets of paper in half. On each half, write one of the conditions needed to see an object—light source, object, eye, and straight path between the eye and the object. Post the sheets on or next to the DQB first quadrant.

Activity 3.2

Students will construct models using materials you make available. A dollar store is a great source for materials. In addition, students may realize through the course of working on their models that they have something from home that would enhance their model. Encourage them to bring these items in the following day. In preparing materials, keep in mind the four things that students are going to need to model and choose objects they might be likely to be able to use. Do not suggest what the items could represent. Simply supply a table of items and let students choose how to represent the components of the model. They will need to model a light source, an eye, an object to see, and a way to show that the light shines on the object and then to the eye. Ideas include yarn and a variety of other craft materials (to show path of light or that light travels), clay or balls (which can be used for the light source, the object, or the eye), animals or dolls (for the object or the eye), markers, and poster board or construction paper (to be cut to represent objects or to use as a base for the group's model).

Safety Guidelines

Refer to IQWST Overview.

Differentiation Opportunities

This lesson has built-in differentiation in its use of different types of models to represent a shared phenomenon students will experience together. The physical, 3-D modeling activity (3.1) allows students to create models in any way they choose. Some will be very creative, and some will use only objects that look like the thing they are trying to represent. For example, some students will use a ball as an eye, and some students will make the ball look like an eye. Some will use a ball as a light source, and some will sculpt clay to look like a light bulb. You will notice that some students actively engage in this activity and some stay more on the sidelines. Often those that do not readily engage will be much more comfortable with the following activity, in which they are given the components to create a 2-D model. Support all students in moving back and forth to connect the actual phenomena (light travels from a source, to an object, to their eye, so that they can see an object), the physical models as one kind of representation, and the drawings as another kind of representation. Each of the models that they develop can be used to explain how people see an object, even though they are very different ways of representing the phenomenon. Students will develop and use different types of models throughout IQWST to explain and predict phenomena, as called for in NGSS, so helping them to understand modeling as a scientific practice, its purposes in science, and that different models can represent the same phenomenon are all important aspects of these activities. The varied ways in which these ideas are approached are designed to help *all* students understand this practice, as well as the content they are using models to learn.

LESSON 3

Constructing Models of How People See

TEACHING THE LESSON

Performance Expectation

Students will develop and use models to explain the role that light plays in how people see objects.

Overview

Activity 3.1
Create 3-D models of the role light plays in seeing, and share group models as a class.

Activity 3.2
Create 2-D consensus models of the role of light in seeing, and use the model to answer questions about light and its behavior.

Building Coherence

In Lesson 2, students developed a class list of conditions that need to exist for an object to be seen. In Lesson 3, students use that list to develop and use models to demonstrate their understanding of how people see.

Timeframe

2 Class Periods

Materials – Introduction

For Each Group
- (1) color comic strip*
- (1) magnifying glass

*This item is not included in the kit.

Introducing the Lesson

Reading Follow Up

Distribute one color comic strip and one magnifying glass to each group of students. Have students use the magnifying glasses to observe the comic strips and talk about what they see with their group members. Ask: "How does what you see with the magnifying glass relate to what you read about in the last reading?" (*The dots they see in the comic strip under the magnifying glass are like the pixels referred to in the reading.)*

- Explain how, even though the words and characters in the comic strip are just a collection of dots, you see words and characters, not dots. *(The dots are too small to see individually without the magnifying glass, but their brains put them together somehow to see it as a character.)*
- In the reading, you learned that a TV combines two conditions needed for sight into one—the pixels make up both the light source and the object. What were the other two conditions for being able to see? *(The other two conditions are an eye and an unblocked path between eye and object.)*

Students will use the ideas they have evidence for about how people see to construct models of how light works.

Discussion – Brainstorming

Purpose

Express initial understanding of models.

Suggested Prompts

- What do you think of when you hear the word *model* in science?
- What are some different examples of models?
- How is a map different from a globe? How is it different from a computer simulation of Earth?
- What is common for a map, a globe, and computer simulation of Earth? *(They can all show some of the same things but in different ways.)*
- Why do we use different models to represent the same thing? *(Each one has advantages and disadvantages. We use the model that best suits our needs at a given time. When our needs change, we may use a different model.)*

Students will now use different materials to build a model of how people see. Talk about the following ideas:

- The purpose of building the model is to help each other think about how a person sees and to share our best ideas about what is happening.
- There is no one right or best model. Different models have different advantages, and no model is perfect. Scientists revise models when they figure out ways to make them better. Creating models takes creativity and imagination for putting something together in a new kind of way.
- Just like different models represent Earth, different models could represent how we see, but all of them need to be consistent with evidence—they need to represent the ideas learned from the investigations. An important aspect of a good scientific model is that it is consistent, meaning it can account for all the existing evidence. *(Use the terms consistency and consistent to help students begin to recognize this as an important aspect of models.)*
- We have evidence of four conditions that need to be represented in the model—a light source, an object, an eye, and an unblocked path between the eye and the object.
- Explain that data may be gathered later about other conditions, but for now, these four conditions, based on the evidence, need to be part of the model.

You might choose to make a chart about the features of models. Record important ideas about modeling as they come up throughout the lesson. Use the chart to remind students about what they have learned. So far, students know that models do not need to look exactly like the thing they represent, but they do need to be consistent with evidence.

Materials – Activity 3.1

For the Teacher
- (2) sheets of paper*
- (1) small light bulb
- (1) small light bulb base
- (1) D-cell battery holder with wires
- (1) D-cell battery
- modeling clay
- (6–8) toy cars
- (1) digital camera* (for photographing group models)

For Each Group
- modeling clay
- small toy cars
- miscellaneous materials* (for students to use to build models)
- rulers*
- paper*
- scissors*
- pens*
- tape*

For Each Student
- Activity Sheet 3.1
- Reading 3.1

*This item is not included in the kit.

Activity 3.1 – Preparing to Develop Models

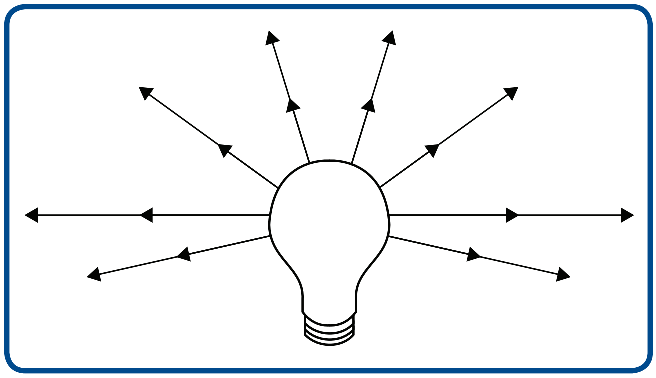
In a place that all students can see, turn on the small, uncovered light bulb. (Note: This light source will be referred to as a bulb throughout the lesson.) Ask the following questions.

- How would you describe the behavior of the light coming out of this bulb? *(Light is traveling away from or out of the bulb in straight lines in all except for the bottom or base, and that light is being continuously emitted.)*
- What ideas about light did the flashlight in Lesson 2 provide evidence of? *(Light travels in a straight line.)*
- How is the light coming out of the bulb different from light coming out of the flashlight? *(Light from the flashlight went in more or less one direction, but light from the bulb goes in almost all directions.)*
- How would you describe the way in which light is coming out of the bulb? Continuously, like a stream of water, or a bit at a time? (*It is continuously emitted.)*

Talk with Students about Models

- Students have some ideas to help explain how light from a bulb behaves. When we use words, drawings, objects, equations, or computers to illustrate or explain ideas about how a phenomenon works, it is called a model.

- There are different ways to illustrate or explain things, and so different models have different advantages and limitations in terms of how they show ideas. Show two different models, and ask students to talk about how they show different ideas more or less clearly.
- Draw on the board a two-dimensional picture of the light bulb with light rays coming out of it in multiple directions.



Next, show students an example of a physical 3-D model of light shining from a light bulb. Use the modeling clay to represent the light bulb and position small toy cars coming out in multiple directions (see picture). The cars represent the light leaving the light bulb in all directions. If available, it may be helpful to put the model on a projector. When you project the model, note that the projection is two-dimensional while the model was three-dimensional. Ask students to relate what they see on the screen to the physical model.

Give students a minute or two to record their ideas on the first part of their activity sheet. Explain that light comes out of a bulb continuously in straight lines in all directions.

- How do these two models do a better or worse job of communicating those ideas? *(Students should identify the following: The drawing shows light coming out in more than one direction but not in three dimensions; it shows light coming out continuously with continuous lines and multiple arrows; it shows that light travels in straight lines but does not show that it is moving. The physical model also shows light coming out in more than one direction, but not in three dimensions; it does not show light coming out continuously, as there is only one car for each light ray; and it can show light's movement in straight lines.)*
- If students struggle to respond to all or part of this question, ask them to evaluate the models in relation to specific ideas. For example, we said that light is coming out of the bulb in all directions. How well does the drawing show this idea? How well does the physical model show this idea?
- Since neither model shows that light spreads out in all directions, how might we create a model that does a good job of showing this idea? *(Answers will vary; students might suggest sticking toothpicks in the ball to represent light rays, or fixing lengths of yarn or string to a bulb, or crumpling yellow paper around the model bulb.)*

As students answer this question, a Think-Pair-Share cooperative learning structure might be useful for eliciting students' ideas. During the Think, have students reflect on the question silently and individually. You may want them to write their ideas in notebooks. During the Pair, have students discuss their answers with a partner. Let students know that each pair will be sharing with the class the ideas they have generated with the rest of the class. During the Share, have pairs report their ideas to the class.

Creating Physical Models of How People See

Now that students have had a chance to look at different models, they are going to build their own physical models of how light helps people see based on the investigations and the evidence.

Refer to the Driving Question Board and the four conditions the class has identified that are necessary to see an object. Students will need to include the four conditions in their models. They will need to make decisions about how to show them in a way that will explain how light helps people see.

Show students the materials available. Groups should decide how they will represent the conditions in a model using the materials available and how they will work together to build a model. The process of identifying important ideas, thinking and talking about how you will represent them, and creating the model is called model construction.

Circulate and ask questions about what students are trying to accomplish. Remind them that the purpose of this activity is to construct the models to demonstrate their understanding (to others) of how they are able to see objects based on the evidence from Lesson 2.

Students require scaffolding when deciding which characteristics of things need to be represented in a model. It will not be apparent at the start if the colors, texture, form, and location of these things are important in explaining how we see. A model should be simple and include only the relevant characteristics to the phenomenon being modeled.

Students need to complete the activity sheet, including a description of the strengths of their model—the ways in which it does a good job of accounting for the data they have collected and the ideas they have developed—and its weaknesses, like any ideas that it does not show as well, or evidence it might not account for.

The purpose of building the model is to provide students an opportunity to represent in a nonverbal manner their explanation of how people see. In this process, they clarify their ideas for themselves. Students' models should show light as follows: (a) in constant motion, (b) traveling in straight lines away from the light source in a variety of directions, (c) traveling in straight lines from the object being seen, and (d) entering the eye. Students' written explanations should include the evidence supporting how the model represents the process of seeing.

You might create an assessment rubric to share with students, or co-create a checklist for evaluating models that you will use and build on as students learn more about modeling.

When groups have finished, have groups briefly share their models with the class. Let them know that they are using models in a way that scientists do—to communicate ideas to others. Communicating will help them clarify their own ideas, learn from others, and practice expressing their ideas.

Suggested Prompts

- How are the four conditions needed for sight incorporated in your model? *(The model should include the light source, the object, an eye, as well as a direct path between the object and the eye.)*
- What are some advantages and disadvantages of the different models? What ideas do the different models show well or less well?

    - The flashlight provided evidence of the idea that light travels in straight lines. How does your model show that idea?
    - The light bulb provided evidence for the idea that light travels out in all directions. How does your model show that idea?
    - The flashlight provided evidence of the idea that light moves from one place to another. How does your model show that light moves?

- The object hunt activity in Lesson 2 provided evidence of the idea that objects can be seen from different locations. How does your model show why you can see the object from several different locations?
- Which parts of your model represent each condition of how people see?

Take photographs of the models. Post them on the DQB or elsewhere in the room along with students' written explanations.

Introducing Reading 3.1 – Modeling

Give students a minute or two to complete the Getting Ready section. For each statement, ask students to raise their hands if they agree or disagree. Have one student with a raised hand and one without talk about why they agreed or disagreed with the statement. It is important that students articulate their reasoning. Follow up the reading in next class period.

Materials – Activity 3.2

For the Teacher
- Use the icons of the eye and light source; prepare two copies of the eye and icon of a triangle*
- (1) object large enough to be seen by the entire class*
- (1) small light bulb and small light bulb base
- (1) D-cell battery holder with wires and D-cell battery
- poster paper*
- copies of Icons for Written Models*

For Each Group
- copies of Icons for Written Models*
- scissors*
- tape or glue*
- sheet of paper or cardstock*

For Each Student
- Activity Sheet 3.1
- Activity Sheet 3.2
- Reading 3.2

*This item is not included in the kit.

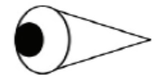
Activity 3.2 – Building the Consensus Model

Reading Follow Up

Have students revisit the statements in the Getting Ready section. Ask: "What changed the way you responded to one of the statements? What in the reading led you to think differently about the statement?" (*It is important that students recognize that [1] models can change, [2] there can be more than one way to model a phenomenon, and [3] all models have advantages and disadvantages. If students are struggling with these ideas, have them revisit specific sections of the reading, looking for support for each of these ideas one at a time.)*

To spark discussion, ask: "What did you think were the best parts of other students' models from the last lesson? What made those parts strong?" *(Answers will vary; it is important that students support their ideas about what was good in relation to the features of models—that they account for important evidence and ideas and communicate ideas and explanations clearly to others without extraneous information.)*

Since physical models are harder to keep and work with, students will now translate their physical models into drawings. Have students use a set of common symbols to represent the four conditions they have established so far. Keep in mind that these symbols are not the only ones that could be used and that they represent a range of things. For example, we could use a light bulb instead of a sun to represent the light source. The coffee cup represents any object that could be seen that is not a light source. Use the symbols in the chart to represent the parts of the model.

Light Source	
Eyes	
Object	
Light Path	→

Give each group a copy of Icons for Written Models and a piece of paper or cardstock. Instruct each group to cut out the symbols and glue or tape the symbols to the cardstock to represent the model they created. (They may need to draw in more lines for the light path.) Give groups time to work and as much guidance as needed, especially revisiting the probing questions (such as "Does your model show X?")

Have students post completed models without their names on them, so everyone can discuss the ideas and not the people who made them.

Discussion – Synthesizing and Pressing for Understanding

Purpose

Evaluate models and refine understanding of what the models must do.

Suggested Prompts

- Ask: "How do the different models show the ideas for explaining how light helps people see based on the evidence we have so far?" Evaluation involves comparing to think about what ideas are shown and which are not, and how different models show particular ideas more or less clearly.
- Ask students questions about individual models and what they show or do not show.
- Ask: "What patterns do you see in how different groups constructed their models?"

  Always refer to the evidence that supports a particular part of a model—if some aspect of a model cannot be supported with evidence the class has so far, it may have to be left out, even if it makes sense.

Once students have talked about what ideas are important and how they can be clearly represented, create one model with which everyone can agree. This kind of model is called a consensus model. As students agree on parts of the model and ways to represent them, use their ideas to construct a consensus model. It is important that the final drawn model looks similar to the Sample Consensus Model, because the model will be used and modified repeatedly throughout the unit.

Discussion – Summarizing

Purpose

Refine the consensus model.

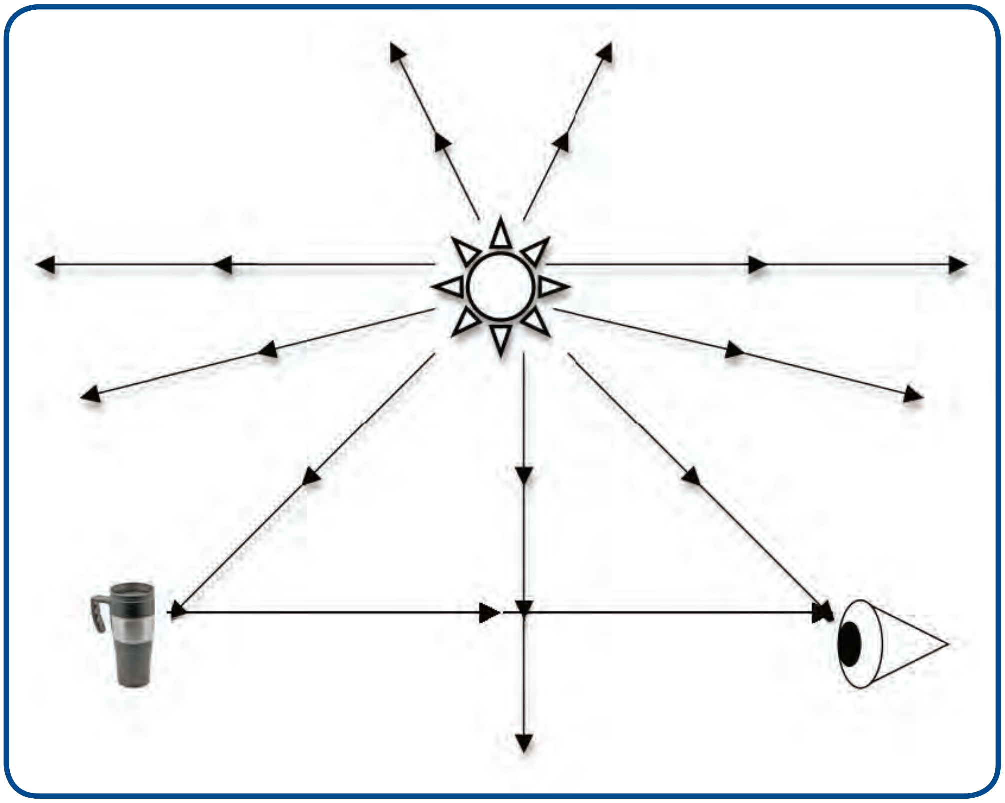
Suggested Prompts

- What do all the models have in common? What are their key components?
- What are differences that you notice between the models? What evidence would support one approach or the other? How should we represent that in our consensus model?
- What ideas do multiple models show? How should we represent that in our consensus model?
- Does anyone disagree with any part of the consensus model so far? How do you think it should be changed? What evidence supports that idea?
- We talked about models having tradeoffs—different models show different ideas more or less clearly. How does our drawn model show important ideas more or less clearly than our physical model?
- How does the consensus model help to explain the first question on the Driving Question Board? It is important that the consensus model represent several key ideas that are based on gathered evidence summarized in the table.

IDEAS	EVIDENCE
Light is continuously emitted in all directions from a light source and travels in straight lines.	uncovered light bulb, flashlight
Some light travels directly to the eye if there is an unblocked path.	light box, "disappearing" finger
Some light bounces off an object and travels to the eye, if there is an unblocked path.	light boxes

Note: In the Sample Consensus Model, light is continuously emitted from the light source. The light source has arrows coming out in all directions. The multiple arrowheads on each line show that light is moving continuously outward from the light source. Some of that light reaches the object. Some of the light that reaches the object bounces off the object and enters the eye. This model can help explain how people see the object. The model also shows light from the light source entering your eyes directly. That is why we can see both the object and the light source. We can see each other, and we can all see the sun or the overhead lights in the classroom.

Sample Consensus Model



Using the Consensus Model

Ask: "How could you use the consensus model to explain why you cannot see the teacher in the other room?" *(There is no path for light to travel between the object [person] and the eye because it is blocked by walls.)* "Now that we have this model to explain how light helps people see, what do you still need or want to know?" *(Students may ask for more details about what happens to light when it reaches the object and how it bounces into their eyes. Respond with a statement like the following: You are practicing an important modeling skill using the model to ask new questions. Your questions will help direct our next investigations into how light interacts with objects.)*

Discussion – Summarizing

Purpose

Bring together ideas about modeling as a scientific practice and about the model itself.

Suggested Prompts

- How were models used to help think about and understand how people see?
- How does the consensus model relate to a camera taking a picture? *(A camera taking a picture operates in much the same way as my eye does. There is light that bounces off objects and then enters the camera just as it would enter my eye.)*

- When it is dark at night, you can still see some things a little bit. How does the consensus model help explain this situation? *(Because it is almost never completely dark, there is almost always some light from stars or buildings that is bounced off objects and enters the eye.)*
- How does our model help us explain how we see things in a television even though the things are not there? *(The television generates light in certain ways that make it look like the object is in the television. The eye detects the light from the television and thinks that the object is there even though it is not, because the light generated looks similar to the light that might have been bounced off the objects had they been there.)*

Wrapping Up the Lesson

- Models can be used to illustrate and explain what happens in a situation; they can be used to predict what will happen, and they can be used to communicate your thinking to others.
- Students should use the consensus model of light to predict what happens in some new situations. So far, they have used models in two different ways: first, to help communicate their ideas to each other, and second, to explain new phenomena.

Attach one of each of the icons to the board, as shown in shown in section 1 of the following figure.

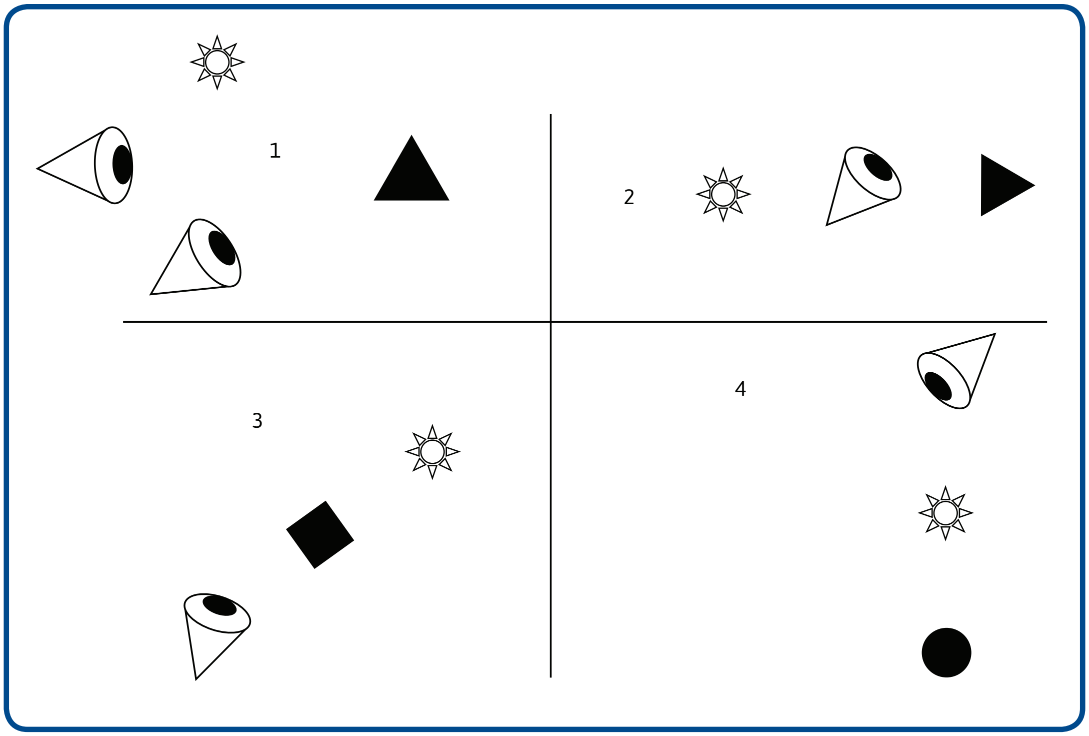
- Will the person (the eye) be able to see the triangle? Why?

Have a student come to the board and add arrows to describe the student's response. Add another eye in a different position (the dashed eye in section 1 of the following figure).

- Will this person see the same thing as the first one? What will they see and why? Have another student add arrows to the diagram to explain the student's response. Rearrange the icons again, as shown in section 2 of the following figure.
- Will this person be able to see the triangle? Why?

Have another student come to the board and explain the student's response. Students can use the object and light source to demonstrate the arrangement.

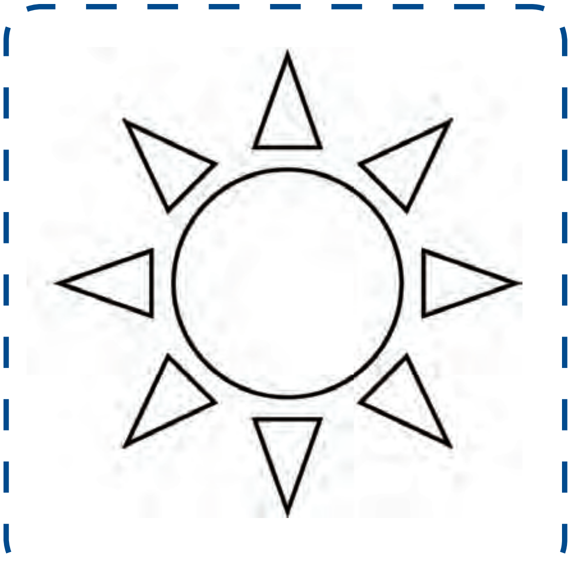
- Does everyone agree with this arrangement? If not, show us how you would arrange it differently based on the diagram. Repeat this sequence with the arrangements shown in sections 3 and 4 of the following figure.

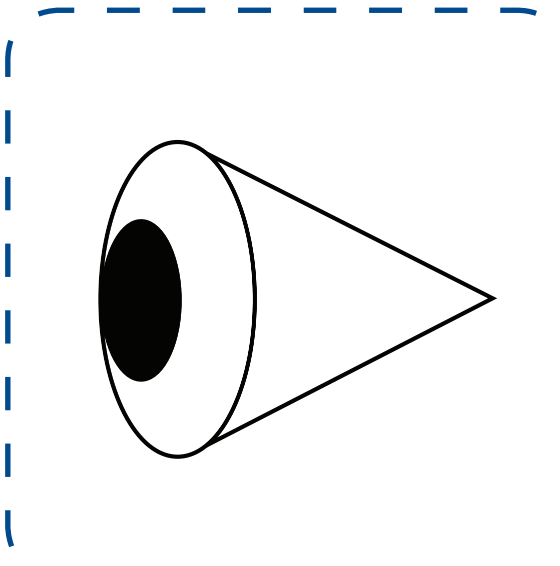


This activity can be used as an assessment to determine whether students still have the alternative conception that sight involves light leaving the eye and to check their understanding of the consensus model. Another possible assessment is to show the consensus model and ask the students to use the model to explain why, if the object had eyes, it could see the eye as well.

Introducing Reading 3.2 – Faster than a Speeding Bullet

One of the reasons people have difficulty understanding that light is moving all the time is because light moves so fast, it seems to go from source to object to their eyes instantaneously. When you turn on the lights in a room, the room seems to brighten immediately with no lag time. Light is the fastest moving thing known to scientists. To help students think about how fast different things move, have them complete the Getting Ready section in class. Have a few students share their ideas and on what they are basing their ideas. (Students may know information about some of these, so it is important for them to be able to share.)
Icons for Written Models





Lesson 4

The Eye as a Light Sensor

PREPARATION

Teacher Background Knowledge

Measuring Light Intensity

Probes measure the light intensity with the unit of lux. It is not important for students to know the definition of a lux. The important thing for students to know is that a higher number means more light is entering the sensor. The Pasco light sensor, for example, has three setting ranges—each with a maximum value.

candle = 0–2.6lux
light bulb = 0–260lux
sun = 0–26,000lux

If students consistently get the same reading, they likely do not have the sensor set on an appropriate range for the light they are measuring. That is, if students repeatedly get a reading of 260 with the light bulb setting, they need to change the sensor's setting to the sun level. Sensors may need to be reset after making a large number of readings, or they may no longer make accurate measurements. Sensors come with written instructions on how to reset them.

Common Student Ideas

During this unit, the text will refer to the device used to measure light as a light sensor rather than the more commonly used light probe. Probing implies that the instrument is seeking out or discovering light. It is important to emphasize that the eye and the device are passive receptors of light; light is reaching them; they are not actively searching for light. Students commonly conceive of light as leaving the eye or otherwise attribute the eye with an active part in seeing. The term *light sensor* is useful, as it does not reinforce this misconception.

Setup

Instructions are given in this lesson for use of a Pasco light sensor and sensor interface. If you have another brand or a different product, adapt instructions accordingly. See IQWST Overview for additional information about probeware in IQWST.

Safety Guidelines

Refer to IQWST Overview.

Differentiation Opportunities

Refer to IQWST Overview.

Lesson 4

The Eye as a Light Sensor

TEACHING THE LESSON

Performance Expectation

Students will use technology to take measurements and analyze data to determine patterns that can explain why certain areas of the room appear brighter than others.

Overview

Activity 4.1

Engage in a light hunt around the classroom using a light sensor.

Introducing the Lesson

Reading Follow Up

An important connection between the reading and today's lesson is the role that scientific instruments play in helping people explore the world and gather data. Ask: "What examples in the reading were about measurements used in science?" *(Speed of people, cheetahs, Peregrine falcons, cars, spacecraft, and light or measurement of time in seconds, minutes, days, or months.)* Two types of measurements and observations are important in science:

- those made using instruments (microscopes, telescopes, stethoscopes)
- those made using only the eyes, as is referred to as made with the naked eye

In this lesson, students compare what they can see with their eyes to what they can measure with scientific instruments. Ask: "Do you know some examples of sensors?" *(Motion detectors, radar detectors, metal detectors, some nightlights, explosive detectors in airports, stud finders in construction.)* If students, struggle, provide an example or two that may stimulate others. Students will use a light sensor today.

Building Coherence

The eye's role in the model students have developed is elaborated as they examine the eye as a light sensor. Knowing how the eye works is essential to answering the Driving Question. Students explore instruments that provide information about phenomena beyond what they can gather with unassisted senses.

Timeframe

1 Class Period

Materials – Activity 4.1

For the Teacher
- (1) projector*
- PI: The Human Eye
- PI: Tracing the Path of Light

For Each Student
- Activity Sheet 4.1
- Reading 4.1
- Homework 4.1

For Each Group
- (1) light sensor, equipped with sensor interface, if possible*

*This item is not included in the kit.

Activity 4.1 – How the Eye Works – Overview

Today's investigations may help answer any questions on the DQB about how the eyes work. Ask: "What do you know about the eyes and how people see?" (Articulating ideas is important; accuracy is not.) Record ideas in a clearly visible manner to return to at the end of the lesson.

Provide a brief overview of the eye using PI: The Human Eye and direct instruction. Students record important ideas on the back of Activity Sheet 4.1. The model of the eye illustrates some of the key parts and their relative locations. Students need to recognize that the pupil is a covered opening through which light travels until it reaches the retina and that the eye detects only light that enters it.

Refer students to their light model. Review the idea that when they see an object or a light source, it is because light is leaving that object or light source and entering their eyes. Replace the object in the consensus model with another object, so students understand that the model can be used to explain how they see any object.

- The eye has a clear opening, called the pupil, that lets light through. In the photograph of the eye, the pupil is the black circle in the center of the eye. The eye is a covered opening—not a hole in the eye.
- Sensors located at the back of the eye (the retina) sense light that reaches them and generate an electric signal, which is sent to the brain through the optic nerve. When a person sees a light bulb, some of the light from the bulb enters the eye and reaches the retina, which transmits an electrical signal to the brain. The brain identifies the signal as being produced by the light from a light bulb.
- If there is also a dog in the room, then some of the light from the light bulb bounces off of the dog. Some of that light enters the eye and reaches the retina where an

electrical signal gets transferred to the brain. The brain identifies the signal as being produced as the result of light from a dog. (*Students may indicate that the unblocked path of light in the model should be revised since light travels through the cornea. If evidence can be gathered to support this, then they will need to revise the model.*)

- A camera works a lot like eyes do. Light comes in through an opening that is covered with something like glass, and then it is sensed by something at the back of the camera, like a device in a digital camera that creates an electrical signal that light was sensed.
- The light sensors students use in this unit are simple. They only sense light that comes from objects at which the sensor is pointed. Like eyes or cameras, light has to enter the sensor in order to be sensed. Instead of generating a signal that is interpreted by the brain as an image, it displays a number that tells how much light is getting into the sensor.

Using a Light Sensor

Demonstrate the light sensor. Connect the light sensor to the data logger, and turn on the logger. The sensor has three sensitivity settings: a candle (can sense weak light), a light bulb (can sense typical indoor illumination), and a sun (can sense intense light). This activity uses typical classroom illumination levels, so the light bulb setting is best. Point the sensor at an overhead light and then at the floor, noting that the numbers are larger when the sensor is pointed at the light than when it is pointed at the floor.

Procedure

- Explain the task. (Use sensors to investigate light and identify patterns in brightness around the room.)
- Make predictions on Activity Sheet 4.1 about what parts of the room will be brightest and least bright.
- Use the light sensors to measure light, gather data (record measurements), and test predictions.
- Analyze data and identify patterns in brightness, and consider why those patterns occur. A light sensor only detects light traveling straight from the direction in which it is pointed (from a light source or bouncing off an object). It does not sense light coming from other directions. Students draw arrows on the activity sheet to show the path of light that enters the sensor.
- Have students describe the path they drew for the first picture. *(Students should describe a path in which light from the source bounces off the object to the sensor, but no light from the source directly reaches the sensor.)*
- Have students describe the path they drew for the second picture. *(Students should describe a path in which light travels directly from the light source to the sensor with no light bouncing off the object to the sensor.)*

Use PI: Tracing the Path of Light to illustrate the light that is detected by the sensor, tracing with your finger the path of light from the source and bouncing off the object.

Discussion – Pressing for Understanding

Purpose

Apply conditions from the consensus model of light to explain readings from the light hunt.

Suggested Prompts

- What patterns did you observe where brightness readings were higher or lower? *(Note the following four patterns:*

  1. *An object appeared brighter to their eyes when the reading on the sensor was greater and dimmer when the reading on the sensor was smaller.*
  2. *Brightness was higher when the sensor was pointed directly at a light source and lower when it was pointed away.*
  3. *Brightness was higher when the sensor was closer to the light source [and pointed at it] and lower when it was farther away.*
  4. *Brightness was higher when there was an unblocked path between the sensor and the light source [or reflected light] and lower when the path was blocked, or when the sensor was pointed at a shadow.)*

- What was the relationship between the brightness you sensed with your eyes and the reading of the sensor? *(When brighter, it was a larger reading; when dimmer, it was a smaller reading.)*
- How did the direction you pointed the light sensor affect the brightness readings? In which directions were the readings the highest? In which were the readings the lowest? *(Readings were higher when the sensor was pointed at a light source.)*
- How did where the light sensor was in the room affect the brightness readings? *(Readings were higher when the sensor was closer to a light source.)*
- How did the position of other objects affect the brightness readings? *(Readings were higher when the path of direct or reflected light was unblocked—the sensor was not pointed at the dark side of an object creating a shadow or at a shadow. Students may also identify that readings were higher when the sensor was pointing at shiny or whiter objects.)*

If students struggle to articulate any of these patterns, investigate the patterns as a class.

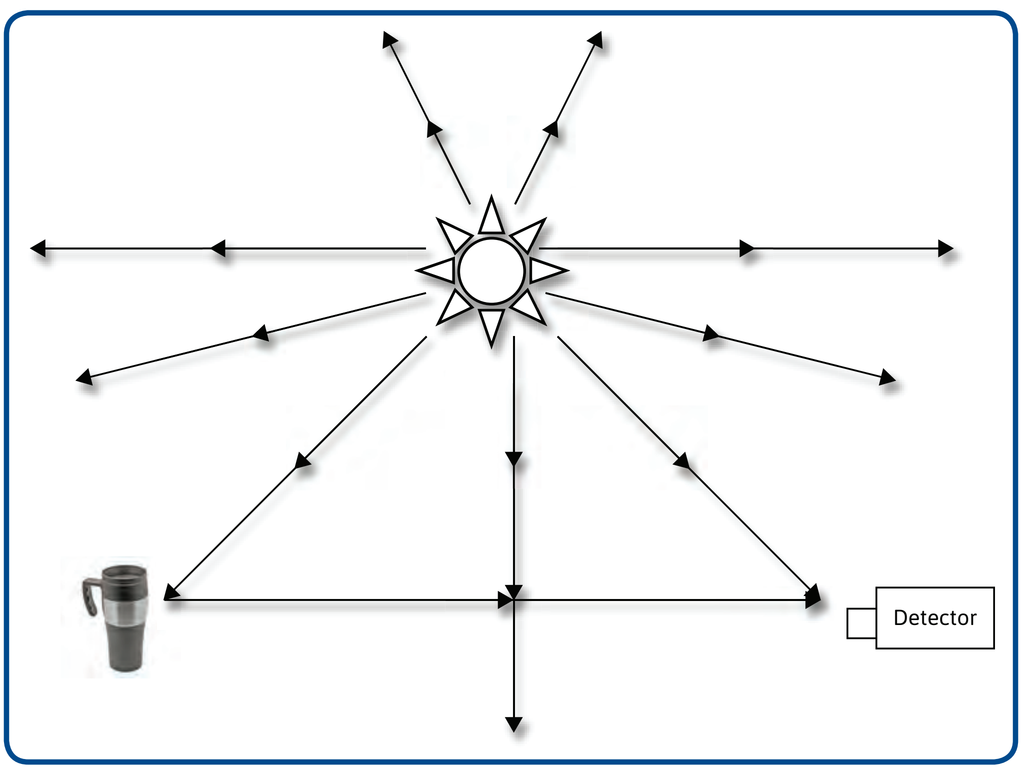
- For the first pattern, keep the sensor in the same place but change the direction in which it is pointing. Students will see the values change even though the sensor is in the same place.
- For the second pattern, hold the sensor near a light source and then slowly walk away from the source. The values will drop dramatically.
- For the third pattern, point the sensor at a light source, then place an object (e.g., a book) between the sensor and the light source. Point the sensor at the floor where light is hitting it, then at the floor in shadow. In both cases, the latter values will be lower.

Suggested Prompts

- Light readings were higher when the sensor was pointed at a light source. Why? *(The sensor is detecting light directly from the light source. More light reaches the sensor from the light source than from other objects.)*
- Light readings were higher when the sensor was closer to a light source. Why? *(Light spreads out from a source in all directions resulting in less light farther away.)*
- Light readings were lower when there was an object between the sensor and light source, or the sensor was pointed at a shadow. Why? *(Light from the light source was blocked by the object.)*

Use the consensus model in which you have replaced the eye icon with an icon for the light sensor (PI: Tracing the Path of Light) to help illustrate students' explanations, or call students up to use the diagram to support their explanations.

- How is the way your eye senses brightness similar or different from the brightness readings taken by the sensor? *(Higher readings look bright or light, and areas with lower readings look darker or shadowy; students might also point out differences like the fact that the sensor does not detect colors or shapes.)*
- What do you see when you look in directions the sensor reads as bright? What do the higher numbers tell you about light? *(Higher numbers mean that more light is entering the sensor. When more light enters your eyes, then you perceive this as brighter.)*
- What do you see when you look in directions the sensor reads as less bright? What do the lower numbers tell you about light? *(Lower numbers on the light sensor mean that less light is entering the sensor. When less light enters your eye, you perceive this as dimmer or darker.)*



- When you point the light sensor at an object, does it detect the object or the light from the object? How does this compare to how your eye works? *(It detects the light coming from the object, not the object itself—this is similar to the eye, which also detects light that has bounced off the object.)*
- What would your eye or the sensor detect if there was no light bouncing off the object? *(Nothing would be detected.)*

You may want to prepare a simpler version of PI: 4.2 (and others throughout the unit) that does not show the arrows. Then, as you discuss the model with students, you can add arrows as you talk through the model.

Return to the list of students' ideas about the eyes created at the start of the lesson. Ask: "What additions, changes, or deletions would you like to make to the list based on what we have learned in this lesson?" (*The eye is a kind of light sensor; light must enter the eye to be seen. Students should justify changes with evidence from the lesson.)*

Wrapping Up the Lesson

Record on the Scientific Principles list the following:

- Light must enter the eye or sensor to be seen or detected.
- The brighter an object appears the more light that reaches the eye or detector from it.

Throughout IQWST, each class should arrive at scientific principles, and they should be worded in students' own language. Although you know to aim for these, if students are not all on board for a principle yet, use further discussion, often including looking at data again as evidence for a principle. See IQWST Overview for more about scientific principles. They should be posted on a class list as well as recorded in the front of students' books, as they will be referred to throughout the unit.

Students have investigated how light moves, constructed a model that shows how light helps people see, and added to their understanding of how the eye senses light. While the consensus model includes a sun, cup, and human eye, it could be drawn with different objects, light sources, or light sensors.

Return to DQB when questions students have asked can be answered based on what they have learned to that point. It is important that students get a sense of what they have learned as they progress toward fully answering the Driving Question: Can I Believe My Eyes? As questions are discussed, students should draw on evidence from their activities. See IQWST Overview for ideas about using students' questions.

The questions at the end of Activity Sheet 4.1 can be answered by students in class or they may be assigned for homework. The second question asks students to use the light model to explain why the direction in which they point the light sensor is important. This can function as an assessment to see if students are becoming proficient at using the light model to explain phenomena.

Introducing Homework 4.1 – Exploring Shadows

Explain that one of the things students noticed in this lesson was that patterns in brightness are related to shadows. In this homework, students look for an example of a shadow and describe it. Review students' observations prior to the next lesson.

Homework 4.1 will be addressed again more carefully in Activity 5.2, after students have spent additional time addressing shadows.

Introducing Reading 4.1 – Eyes in the Animal Kingdom

Reading 4.1 reviews information from class and introduces some of the ways in which animals' eyes have adapted to allow them to see better in their particular environments. It includes an activity for students to do at home where they look at a pet or a family member's eyes as the lighting goes from dark to bright. The activity could be done in class with students looking at each other's eyes.

Students will read about the eyes of three animals: polar bears, cats, and a giant squid. They will write a summary about animal eyes at the end of the reading. In the next class, they will discuss the important ideas they included in their summaries. Spend time teaching students about writing a good summary, or enlist the support of the language arts teacher in helping students with this skill (which draws on elements of the Common Core).

Lesson 5

How Are Shadows Created?

PREPARATION

Teacher Background Knowledge

Bouncing and Blocking Light

So far, students have thought of objects only as things that bounce a source's light to the eyes. Now they will consider that by bouncing light, the same objects also do something else—they block the light from continuing in its original direction. Students already considered that objects block light—see PI: What Hinders Sight?—but the combination of bouncing and blocking is new. This change might be difficult for students who have not thought about this before. Remind students of the dividers in the light boxes. Although they blocked the light that was bounced by the statuettes and thereby prevented them from seeing the statuettes, they could see the dividers, which meant that they were both blocking light from the statuettes and bouncing light from the source to the eyes at the same time. Therefore, the dividers were both obstacles blocking light and objects being seen at the same time.

Models and Modeling

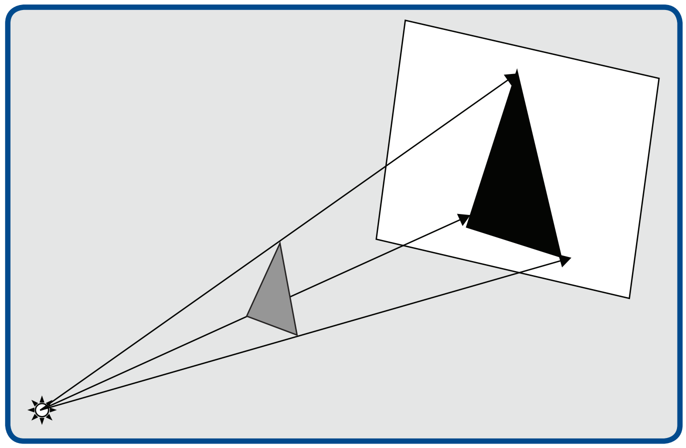
Although daily experiences with light and sight occur in a three-dimensional world, the light model is drawn in two dimensions. In this lesson, figures are drawn in perspective in order to try and highlight the three-dimensional world in which shadows are formed. Clarify to students that these two-dimensional drawings made in perspective are just different representations of the same phenomena and are not intended to be exact replicas of reality. Some students may find two-dimensional drawings easier to understand, and others may understand the perspective drawings better. In either case, students may still have an unclear understanding of the relationship between the models and the real world. Help students understand that both models are just representations of phenomena that are not easily visible.

Shadows

A shadow is formed when an object blocks the path of light. What people see is only the light reflected from the area around the shadowed area. What we see when we see a shadow is the absence of light in the shadowed area. In reality, there is usually some ambient light, so there is probably some light reflected off the shadowed area. (For example, in Lesson 9, students will use the light sensor to measure the intensity of the light coming from a shadowed area. They will not get zero reading, though the intensity will be much lower than that from the surrounding areas where the shadow is not cast.) In this lesson, students consider the ideal situation of a shadow created with one small light source. Reading 5.2 describes the more typical situation where a large light source, or more than one source, illuminates an object and creates a shadow.

The shape of a shadow depends on the shape of the object, its orientation related to the light source, and the orientation of the surface on which the shadow appears. The size of a shadow depends on the distance between the object and light source, and the distance between the object and the surface on which the shadow appears, but it does not depend on the intensity of the light source. The size and shape of the shadow can be predicted by using the light model.

In this lesson and in Lesson 9, students will be changing the location of an object and observing the change in the size of the shadow. They will find that when the object is closer to the light source and farther from the surface, the shadow will be larger, and when the object is closer to the surface and farther from the light source, the shadow will be smaller. The shape of the triangle will remain the same; only the size changes.



The diagram shows how the light model can explain the size and shape of a shadow. By tracing straight lines along the edges of the triangle all the way to the surface, the shape of the shadow will be formed. If the shape were to be pulled closer to the light source, the shadow on the surface would have to be larger to account for the change in angle of the lines. An analysis like this is what students should be able to do by the end of the activity—using the model to explain why the shape of the shadow changes when the position of the object changes.

Students will probably not realize that that are using their models to (1) make sense of how shadows are created in terms of the relationship between the light source, object, and its shadow, and (2) generate explanations and predictions about shadows' sizes and shapes. While students are manipulating the distances between the light source, the object, and the surface (i.e., the shadow's location), make these uses of the light model explicit for students so that they are aware of what they are doing—that is, using the light model to generate ideas, make sense of phenomena, make predictions, and explain ideas to others. If you are using a chart depicting the features of models, use it to support these points.

Common Student Ideas

Shadows

- Students who hold misconceptions regarding how people see might not be able to accept that a shadow is the absence of light and believe there is some light at the place of the shadow.
- Students who do not connect shadow creation with light may say that darkness (or combination of light and darkness) is needed to see a shadow. In this case, ask what they mean by darkness. No light sources? Will it be possible to see anything without a light source? Shadows can be seen outside even though there is light coming from the sun.

- Students may think of a shadow as the presence of something that light allows people to see, rather than as the absence of light.
- Students may believe that the shadow is something that exists independently of an obstacle and a light source (like the shadow in the story Peter Pan). They may say that the shadow is always behind a person, even if the light source is on the same side. This belief may be different for shadows of humans and of inanimate objects.
- From observing their shadows during the day while the strength of the sunlight appears to be changing, students may believe that the intensity of the light source influences the size of the shadow.

Setup

Specific instructions for activity setup are embedded within the lesson.

Safety Guidelines

Refer to IQWST Overview.

Differentiation Opportunities

1. If the students did Homework 4.1, in which they looked for shadows outside, they may get confused by the fact that the shadow of their body or of a tree appears to be connected to their body or to the tree, while shadows made in class or as depicted by the light model appear to be separated from the object that created them. You may need to spend some additional time providing known examples and using in-class examples to help students with this confusion. In the model and in class, the surface on which the shadow is projected is not connected in any way to the object making the shadow. Outside, the ground serves as the surface, and the ground is connected to the object making the shadow. The shadow of an airplane or of a bird outside will not be connected to the object. Likewise, if you rest your arm on a table in class, the shadow it makes on the table will be connected to your arm. So the connectedness of the shadow and the object has nothing to do with inside or outside, just the location of the surface relative to the object. Advanced students might develop a model that explains how a shadow is made in a situation where the viewing surface is connected to the object.

2. This unit contains the first in a series of readings about the universe and the solar system (Reading 5.3), as they deal with light-related characteristics and phenomena. This unit can be taught without incorporating this material; however, the readings are included to describe phenomena that can extend students' understandings of the concepts addressed in the unit. The readings are also included to address NGSS as related to space science, but in a context related to other core ideas and crosscutting concepts. The readings are thus included without corresponding activities. You may wish to require only the readings, to require the readings of only some students, to make these readings optional for all students, or to accompany them with activities. However, take care not to stray from the learning goals and performance expectations of this unit, as the readings' primary purpose herein is to support those goals.

Lesson 5

How Are Shadows Created?

TEACHING THE LESSON

Performance Expectation

Students will use the model of light and seeing to explain how light interacts with matter to form shadows.

Overview

Activity 5.1

Examine shadows.

Activity 5.2

- Modify the class light model to represent how shadows are formed.
- Review Homework 4.1.

Reading Follow Up

- Ask: "What did you learn about how some animals' eyes are different from humans' eyes?" *(Polar bears have a clear covering that protects their eyes; cats have more sensitive retinas, pupils that make slits, and protective coverings like polar bears; and giant squids have the largest eyes of any animal.)*
- In your summary, ask: "How did you describe how different animals' eyes work?" *(How animals' eyes work depends on where they live during the day or at night, or in what situations they need to see, such as deep in the ocean or in caves. It is important to make connections between the way the eyes work and the environmental conditions in which they function.)*
- Ask: "Can an animal have an eye that allows it to see even when there is no light present? Why?" *(The eye, because it senses light, could not play a role in seeing without light. Students might suggest the possibility of an eye that senses something other than light.)*

Building Coherence

This lesson bridges Learning Sets 1 and 2, providing an opportunity to use the model of light and the experience with light sensors to explain the phenomenon of shadows. The idea that light travels in a straight path will be checked, and the need to consider what happens when light reaches an object will be raised as a justification for the transition to Learning Set 2.

Timeframe

1 Class Period

Introducing the Lesson

Discussion – Connecting

Purpose

Relate the four components and relationships of the light model to shadows.

Suggested Prompts

- During the light hunt, where did you see differences in the reading of the light sensors? *(The sensors detected different light intensities in different locations [closer to or farther from a light source] and when they were pointed in different directions [toward or away from a light source or reflected light].)*
- The light source in the consensus model is represented with a symbol that looks like a sun. Does this mean the only light source that helps people to see is the sun? Why? *(The symbol represents any light source, and light from any source will help them to see. If students struggle with this idea, think about replacing the sun with a light bulb, and whether the change in symbols changes how the model works.)*

Remind students that models are designed to represent things in the world, and they need not necessarily look like these things. The sun symbol does not just represent the sun, but anything that is a source of light. The mug represents any object that can be seen and is not itself a light source. Although the model only shows a few light rays of light in several directions, the light rays represent many light rays going in all directions.

- In the model, light rays are shown moving to the eye directly from the light source—what does that represent about what people see? *(Light going directly from the source to the eyes is how people see the light source itself, like looking at a light bulb.)*

Materials – Activity 5.1	
For Each Group • (1) MagLite™ or flashlight	***For Each Student*** • Activity Sheet 5.1 • Homework 5.1

Activity 5.1 – Introducing Shadows

Discussion – Brainstorming

Purpose

Share ideas based on the model about what happens when an object blocks the path of light.

Using the icons from Lesson 3 and a rectangular symbol to represent a blocker, create the following situations on the board, have students talk in pairs about their ideas, then ask students to share with the whole group what they think would happen.

- Will the eye still see the object if the path from the light source to the object is blocked? *(Some may think that light fills the room and does not have to reach the object.)*
- Will the eye still see the object if the path from the light source to the eye is blocked? *(Some may say the eye needs some direct light from the light source in order to see.)*
- Will the eye still see the object if the path from the object to the eye is blocked? *(Some may still not understand that light must enter the eye in order to see.)*

Dim the lights. Explain that students have done some initial thinking about how people's sight might be affected when light is blocked. To test and refine some of their ideas, students will gather data about what happens when the path of light is blocked by an object. In this case, the flashlight will be the light source, and a hand the object. Challenge students to explore how a shadow is made.

After a few minutes of unstructured exploration, students answer the questions on Activity Sheet 5.1 in groups, and then discuss them as a class.

- What is needed in order to create a shadow? How can you test that?
- What happens to the shadow when you turn off the flashlight?
- What happens to the shadow when you take your hand away? Use a flashlight to project a shadow of your hand on the wall.
- How could I change the shape of this shadow?
- How could I change the size of this shadow?
- How could I change the location of this shadow?
- Can you see the same shadow from different positions?

Have students draw the shadow of their hands and describe where the flashlight was located relative to their hands and the shadows.

Homework 5.1 – A Midnight Crime

Homework 5.1 is a short story about a crime that happened at night. An officer questions someone who describes what happened, but his description includes many details that do not make sense. These details are connected to a conceptual understanding of shadows. Students should be able to answer some of these questions now, but it is possible that they will still have difficulty with others (e.g., drawing the right shadow in Question #2. Activity 5.2 will support students' understanding, but this homework will be followed up in Lesson 6.)

Homework for Use in Activity 5.2

In Homework 4.1, students were asked to look around their home for shadows and draw them. These will be used for Activity 5.2. If you did not have an opportunity to assign this homework, have students use instead the drawing of the shadow of their hands they drew at the end of Activity 5.1.

Materials – Activity 5.2

For the Teacher
- (1) projector*
- PI: A Light Model
- PI: Light Model 2
- PI: Shadows

For Each Student
- Homework 4.1
- Activity Sheet 5.2
- Reading 5.2
- Reading 5.3

*This item is not included in the kit.

Activity 5.2 – Connecting Shadows to the Light Model

Show PI: A Light Model. This image focuses only on the light reaching the vicinity of the object; for this reason, all the arrows leaving the light source are dimmed except those that reach the object and are bounced from the object to the eye. Explain that this image shows a representation of the light model designed to help them think about how people see shadows. Call attention to the model's four conditions determined necessary for seeing: a light source, an object, an eye, and an unblocked path.

- Prepare a version of this projected image, and all the others in the unit that are based on the model of light with simpler versions without the arrows, and then add arrows to the projected image as you discuss the model with the students.
- Review Homework 4.1 at this point and as part of the following discussion.

Discussion – Pressing for Understanding

Purpose

Determine what is needed to see a shadow.

Suggested Prompts

- When you made shadows with your hands (or when you observed shadows at home), what was needed to create a shadow? *(In addition to a light source and an object, they also need a surface on which to see the shadow [paper or ground for example]. If students struggle to identify the need for a surface, do not spend too much time on this; it is fine to mention this component of the model to them.)*
- Where is light blocked or unblocked in the model of seeing a shadow? *(The object blocks some of the paths from the light source to the surface, but not everywhere; there are also unblocked paths from the light source to the surface past the edges of the object. There are also unblocked paths from the surface to the eyes and from the light source to other directions. So for a shadow to be made, both a blocked path between the light source and the surface and unblocked paths of light are needed.)*
- How could you test if a path of light is blocked or not? *(They can use their eyes to see if the light is blocked, or they can do the same with a light sensor. Remind students about the light hunt, and ask if the light sensor showed any differences between shadowed and lit areas.)*

Write on the board the conditions needed to create a shadow: a light source, an object, and a surface.

- If there is no light being bounced off from a shadow that can enter the eye because the light is blocked, how do people see a shadow? *(If there is only one small light source making the shadow and no other background light, the shadow itself will be completely dark [no light reaches it], so it cannot be seen. However, the area around the shadow is illuminated, so that can be seen. A shadow can be seen by inferring its existence from the absence of light. Realistically, there is almost always some background light, so the shadow is not completely dark and can be seen a little bit.)*

Continue to display PI: A Light Model and read the directions on the activity sheet together. Ask students to think about how to use the model to explain how a shadow is formed and seen. This is one way for students to test the usefulness of the model. If they can use it to explain this new situation, they have identified another way in which it is useful for explaining phenomena and communicating those ideas to others. If not, they will revise or add to it, so that it does. One feature of models in science is that they are always being evaluated and revised to account for new ideas and new evidence.

On the activity sheet, have students use the picture being projected as a reference to draw in light rays that show how a shadow is made and seen on the surface that is shown.

This activity can be used as an assessment to see students' preliminary understanding of how shadows are formed and seen. The homework drawings, the drawings on the projected images, and the drawings at the end of the lesson can be compared to see how students' understanding of the light model for shadows is developing.

Call volunteers from two or three groups up to the board to show the model their group constructed to explain how to see shadows. As they present, encourage the rest of the students to think about how the model being presented is similar to or different from their models.

Do you agree or disagree with what this model shows? What parts do you agree or disagree with and why? Be sure to refer to evidence or ideas from the previous investigations.

Have students refer to what the model shows or does not show rather than what the group did or did not do. It is to be expected that variations will appear. If students show alternative ideas, like the shadow is on the same side of the object as the light source, ask them to explain how they decided about the location of the shadow, and whether it will change if the light source will move. Ask students to suggest ways to investigate if their models can accurately explain how shadows are created and seen.

PI: Light Model 2 represents the model students should construct by the end of the lesson.

Homework Follow Up

In the Midnight Crime, students were asked to identify impossible details in the story, as indicated on the annotated teacher version. Students can answer some questions using the consensus model at this point.

- What did you identify as one of the impossible details in Mr. Jones's story, and what ideas about how light allows people to see explains why it is impossible? (*The shadow would have gotten smaller, not larger, as the person moves away from the light source and toward the surface. Also, Mr. Jones would not have been able to see the details on the box if it was dark outside.*)

- If you have time, reenact the story of the crime in the classroom. Darken the room, and using a single flashlight (representing a car's headlight), have a student walk in front of the light and toward a wall at which the light is pointed.

Wrapping Up the Lesson

Discussion – Summarizing

Purpose

Recount the main ideas for how shadows are made and how people see shadows.

- How is light involved in creating shadows? *(Light is blocked by an object, and only rays that were not blocked by the object reach the surface.)*
- How is light involved in seeing shadows? *(The light that reaches the surface around the shadow bounces to the eyes.)*
- How is seeing an object similar to or different from seeing a shadow? *(Both require light to be bounced to the eyes, but seeing an object involves detecting light coming from the object itself, while seeing a shadow involves detecting light bounced from around the shadow but not from the shadow itself.)*
- Using the model, what would you predict a light detector would detect when pointing toward the shadow on the screen? *(It would detect nothing, as no light reaches the shadowed area, and no light is bounced to the sensor to be detected.)*
- Will you see a shadow if there is no surface? Why?

The goal is that by the end of this lesson, students will understand that they see a shadow indirectly. That is, they see the illuminated area around the shadow and imply the existence of a shadow because there is less illumination there than in the surrounding area. Since no light reaches the shadowed area from the light source, less light is bounced back to the eyes from this area than from the surrounding area that is illuminated by the light source.

Add the following four new principles to the Scientific Principles list and to students' lists in their books:

- Light travels in straight lines.
- Light continues traveling until it reaches an object.
- A shadow is formed behind an object that blocks the path of light.
- A shadow is seen when less light reaches the eyes from it than from the area surrounding it.

Direct students' attention to the DQB.

- How does what you have learned about shadows help you think about the Driving Question: Can I Believe My Eyes?
- If a 10ft. shadow of a cat is on a wall, can I believe my eyes that there is a 10ft. cat in front of a light? Why?
- If a shadow that is shaped like a monster is on the wall in my room at night, does that mean I should believe my eyes that there is a monster making a shadow? Why?

- What questions on the Driving Question Board can you now answer that were part of the first learning set investigated?
- What questions have not been answered yet?
- What other phenomena can the light model be used to predict or explain?
- How can you use the light model to explain how you saw or did not see the strange images from Lesson 1?
- What does the model predict will be seen in a completely dark room?
- What phenomena related to light and seeing can the model not explain?
- What do you still not understand about the strange images from Lesson 1?

Explain that scientists use models to explain, make predictions, and come up with new questions. This is a good place to have students add to their Driving Question Notes anything they learned that they think is relevant to answering the Driving Question.

Note: The following questions provide a bridge to Learning Set 2, if students have not already raised questions about transparent materials.

If time allows, demonstrate the shadow of a transparent object using the projector.

- What would happen if the object creating a shadow was made of a transparent or clear material?
- What does the model currently explain about how light interacts with transparent materials? Explain that this is an important phenomenon that the model does not yet explain. In the next set of investigations, students will collect data on how light interacts with different kinds of materials, including transparent materials.

Introducing Reading 5.2 – All Shadows Are Not the Same

Ask students how they think having more than one light source—such as two lamps in a room—would affect the shadows they see. This reading is complex, and you may choose to review it in class, supporting students in connecting what they see with the corresponding model that can be used to explain how they see what they do.

Introducing Reading 5.3 – Stars and the Solar System

Reading 5.3 provides an overview of the Milky Way galaxy and the solar system. It focuses on how people see stars and planets and why typical models of the solar system are often misleading.

The material in this lesson must precede the other astronomy-related readings, as they will build on the content of Reading 5.3. (See the Differentiation Opportunities section in Lesson 5 Preparation for information on using this reading.) Have students focus on conceptual understanding by suggesting that the topics you will discuss later are how we see stars at night but not during the day and why planets cannot be seen during the day.

Lesson 6

Scattering and Reflection of Light

PREPARATION

Teacher Background Knowledge

Reflection and Angles

The activities were written without the expectation of prerequisite knowledge of angles; however, they provide an opportunity for students to practice and demonstrate their understanding of angles. Before you begin this lesson, consider speaking with the mathematics teacher(s) to find out what students have already learned about angles. Likewise, the math teacher(s) may want to refer to this lesson when introducing or teaching about angles.

The law of reflection is that the angle of incidence equals the angle of reflection. If an incoming light beam makes a 45° angle with a mirror, the light beam leaving the mirror will also make a 45° angle. A light beam coming in at an angle of 10° will leave, making a 10° angle with the mirror.

It is not necessary to define angle of incidence or angle of reflection for students. The exact angles are also not important. However, students should notice that the maximum reading on the light sensor occurs when the two metersticks appear to make the same angle with the wall, for example, when both the flashlight and sensor are at Position 2 to the left and at Position 2 to the right of the center line on the activity sheet.

Student Investigation of Angles

When a flashlight hits a piece of paper, it does not produce the predictable pattern that you see with the mirror because of the paper's surface. In lesson 6.2, the data tables are set up to compare the mirror and paper patterns when the flashlight is at Position 3, and the focus of the sense-making discussion is to help students see this difference, and to ask *why*. Although students might have already guessed that light bounces differently off of a piece of paper and a mirror (through their own everyday observations or because of the demonstration in the beginning of Lesson 6), they now have evidence for reflection and scattering. The magnified view of the piece of paper is an important piece of evidence to help students conjecture about how light rays interact with the surface of these two objects to produce these different patterns, and allow them to see their reflection in a mirror but not on paper.

These activities work best with a flashlight that enables students to narrow (focus) the beam. It may be helpful to have students report and compare answers after the first measurement (Position 1). At this point, check setups if students have vastly different results, for example, because their positioning is not precise. In any case, there is much room for human error in this lab, so you might choose to take the average of results, or you might choose to focus primarily on what the trends in the data show as to the two different patterns.

Limitations of Models

Models are simplified representations of phenomena. As such, some details of a phenomenon are not addressed by any given model. This may or may not be a drawback, depending on the model's purpose. The model of the role light plays in vision is useful in helping us understand and explain how light travels—that light travels outward from a light source in all directions until some of it reaches an object, and some of that light is bounced toward our eyes where it is detected. However, if we want to understand how our eyes detect light, the current model is not very useful, because it does not include details about the eye. For that reason, in Lesson 4, students learned more about the eye in the model and provided additional details that helped explain how the eye detects light. The model of the eye used in that lesson can be thought of as a separate model on its own or just an enlargement of part of the model of light.

In the same manner, the model of light is not useful in understanding how light bounces from different objects because it does not provide enough details about the characteristics of the objects. For that, students need to learn more about the object in the model, and to understand details about its surface features. Some additional characteristics will be explored in Lessons 7 and 11.

The drawing with the symmetrical "V" that appears in the checkpoint is an example of a model (or an enlargement of the object in the model of light) that represents the way light interacts with an object when the object has a shiny surface. At this time, you will discuss only surfaces with students. Next, students will explore the difference between shiny and dull surfaces.

Data from the Investigations

Support students in creating a simple, two-column data table in which to organize and record their data from investigation 6.2. As they think about the task, what data does it make sense to record? How does it make sense to label the rows and columns in a table to organize those measurements? Sample data tables are provided on Activity Sheet 6.2 in the teacher materials.

Analyzing Data

Students should notice that the measurements for the mirror were near zero at all positions, except Position 3, where it was a very high reading producing a peaked pattern. Also notice that the measurements for the paper were more constant, perhaps with a slightly elevated value between Positions 3 to 5, producing a constant pattern. Finally, notice that Positions 1, 2, 4, and 5 were higher for the paper than they were for the mirror. This is because a mirror has a very smooth surface, and a sheet of paper is made of very fine fibers that are randomly oriented. When light hits each one of the fibers, it bounces off according to the law of reflection, but because the fibers are randomly oriented, making the paper's surface rougher than the mirror's surface, the light is scattered in all directions rather than reflected as a defined beam.

The light sensor readings in the sample data tables were collected under ideal conditions; do not be surprised if classroom readings are significantly lower. Numerical values depend on the strength of the flashlight used, ambient light in the room, and how precisely they have aligned their flashlight and sensor. The purpose is to note patterns in the data, not to collect measurements that align with those given in the sample data tables.

The reading at Position 3 should have a distinctively higher value than at the other positions when the mirror reflected the light. This is an indication that most of the light from the flashlight was reflected to Position 3, as required by the law of reflection. Light being scattered from the paper should produce a more evenly distributed set of readings at the different positions.

How Surfaces Affect Reflection

Students should be able to guess that images can be seen in a mirror because light is uniformly reflected off a mirror, while light is scattered off a piece of wood, and that the difference is caused by the smoothness or roughness of the surfaces. Students are unlikely, however, to explain why an image is formed when you look at a mirror, but not when you look at wood. An image is formed by a mirror because the light rays are all reflected in an orderly fashion. Since all of the light rays are reflected in the same way, with the same V pattern at the smooth surface of a mirror, an image appears as if the object were positioned behind the mirror. When light hits wood, each light ray still strikes and bounces off the wood with a V, but the rays are scattered because the wood surface is rough so that no coherent image exists because the rays have been scattered with the different V angle sizes. While you can see light coming off of the wood, it will be diffused and will not form any sort of image.

Detailed Information about Reflection and Scattering

To keep a curriculum age appropriate, middle-school materials must sometimes address phenomena in a way that seems not completely accurate because it is, indeed, only part of the story at this level. When light hits a surface and is reflected, the angle of reflection is caused by two things: the roughness of the surface (which is the explanation presented in IQWST and is intuitive and appropriate for middle schools) *and* the depth that the light succeeds in penetrating beneath the surface together with the structure of the material from which the surface is made (which is not presented in IQWST). Think of an example where an object is highly polished, such as a gem stone, a piece of marble, or even a mirror. If the surface was perfectly polished, we should not be able to see the surface itself, just objects that are reflected in the surface. But we do see the surface. This is because not all the light is reflected by the surface, but some of it penetrates under the surface and is scattered there.

When you think of a piece of paper instead of a mirror, there are two things happening. First, light is being scattered from the surface as is taught in IQWST. Its intensity should be very even with a slight peak at an angle of scattering that is equal to the angle of incidence. This should occur at Position 3. Second, light is being scattered from below the surface. The distribution of this light is different and follows what is called Lambert's cosine law. This distribution is not very even, with a peak perpendicular to the paper and decreasing intensity as the angle of scattering decreases when measured from the surface (Position 6 in the experiment 6.2). Therefore, the actual distribution of scattered light is a combination of these two distributions, ending up with the maximum somewhere between Positions 3 and 6. Where exactly it will be located depends on the nature of the substance from which the light is being scattered.

What is important for the students to understand in the case of scattering is not so much where the maximum is located (the difference in intensities is so small that you really have to look for a peak to find it), but that the light gets scattered in all directions. This is unlike the case where light is reflected from a mirror, so we get similar light intensities at all positions, rather than a clear peak in one position and almost nothing at all other positions.

Introducing Reading 6.4 – Moon Phases

This is the second reading on astronomy. If these readings are being incorporated into this unit, both Reading 5.3 and Reading 6.4 should be completed before the end of Learning Set 2. To introduce the reading, ask students to think about the sun, earth, and moon. Do any of them go around another? Ask a volunteer to draw on the board a model of how these three objects move relative to each other. How do people on Earth see the moon?

Like all models used to represent and explain phenomena, the models students draw (or the models in their books) have limitations—the relative sizes of the objects are not accurate. The sun should be 300,000 times bigger than Earth. The distances between Earth, moon, and sun are also inaccurate.

Common Student Ideas

Shapes of Objects

When asked how people see the shapes of objects, students might explain that people's eyes see the shape of an object or light rays that enter people's eyes carry images. The scientific explanation for how people see the shapes of objects is that people's eyes detect the shape of an object based on the direction from which the light reflected off it comes to their eyes. The scientific explanation explains both how people see shadows and how Mr. Jones (in the homework activity) could not see the details on the box. In this lesson, students will collect evidence that can be used to explain why the direction of light rays bouncing off an object to their eyes depends on the surface properties of different objects.

Shiny vs. Nonshiny Objects

Students commonly depict light bouncing off shiny objects and mirrors but not off other nonshiny objects. For example, students might say that light does not bounce off opaque objects like walls; instead, light appears on the wood. This confusion typically arises because shiny objects, like mirrors, uniformly reflect light and can produce an image of an object other than itself, while things that are not shiny, scatter light and produce only its own image. For example, a person can see a wall because light has been scattered from the wall to the person's eye. If you can see an object, that is evidence that light has been scattered by the object. On the other hand, you do not see images in a wall because the light has been scattered by the wall, not reflected. Activity 6.3 introduces the relationship between smooth and rough surfaces to account for the difference between scattering and reflection.

Smoothness

Students may think that the surfaces of paper and the mirror are both equally smooth. To the touch of a finger, both surfaces are very smooth; but to a light beam, the surfaces are not equally smooth. One way to discuss the difference of how smooth or rough the surface is to use this analogy. If you bounce a ball off a paper or a mirror on the floor, the ball bounces back to your hand. The surface of the mirror and paper seem equally smooth because the ball bounces straight back. Because light rays are much smaller than a ball, they are more sensitive to small differences in surface smoothness than the ball. To introduce scattering, ask students what would happen if the ball were to bounce off a pile of bricks. The ball bouncing off bricks is similar to the effect of light bouncing off the paper fibers.

Setup

Activity 6.1 and 6.2

Set up the lab apparatuses for Activities 6.1 and 6.2 ahead of time. Be sure that students' questions relevant to the second learning set are grouped on the DQB. Questions such as the following might be included: Why do colors fade in the sun? How do mirrors reflect things? How come you can see through a window, but if you look closely you can also see your reflection at the same time? Why do plants need sun, but then if they get too much sun, they die? Why does the sun make people sweat? Why does metal get so hot in the sun? Why do some things melt in the sun, but other things do not? Why do clothes on the clothesline dry faster when it is sunny outside? Why does the sun make my whole house hot?

Activity 6.3

Reading 6.4 may be assigned any time after Lesson 6 is finished, but it does not need to be completed immediately at the conclusion of Lesson 6. In Lesson 7 (prior to Activity 7.1) you will find directions for *Reviewing Reading 6.4*. This is a separate activity, not simply a typical reading follow up. Use this reading and review as best fits your schedule and your students' learning needs.

Safety Guidelines

Refer to IQWST Overview.

Differentiation Opportunities

Advanced students or students particularly interested in space science might pursue individual aspects of the ideas in Reading 6.4 as independent projects in which they report back to class, write reports from information they gather (addressing elements of the Common Core related to independent text-based research projects), or create representations in any one of a variety of forms about what they learn.

Lesson 6

Scattering and Reflection of Light

TEACHING THE LESSON

Performance Expectations

Students will

- use technology (a light sensor) to measure light intensity, construct data tables to organize data, and analyze and interpret data to explain why some objects scatter light while others reflect it.
- construct and use a model of light reaching an object to represent the law of reflection and scattering and to explain why people can see their reflection in a mirror but not in a sheet of paper.

Building Coherence

In Learning Set 1, students developed a model of seeing that included light bouncing from an object and entering the eye. In Learning Set 2 (Lessons 6–9), students use and revise the model to explain different ways light interacts with an object. This lesson introduces students to reflection and enables them to distinguish between two ways light bounces from an object: reflection and scattering.

Timeframe

3 Class Periods

Overview

Activity 6.1

Use light sensors to track light from a flashlight after it strikes a mirror.

Activity 6.2

Compare light after it bounces off a sheet of paper to light bouncing off a mirror.

Activity 6.3

Explain why people can see their reflections in a mirror, but not in a sheet of paper.

Reading 5.2 Follow Up

You may choose to spend class time doing a careful review of Reading 5.2 with students, especially helping them to connect what they see in the real world with the representations in the reading. One way to do this is to have students look only at the diagram as you read some of the text aloud, or describe what the diagram shows as they look at it, so that they interact with the information through two channels—sight and hearing—simultaneously.

Reading 5.3 Follow Up

For homework, students read an overview of the relationship between the planets and the sun in the solar system, the Milky Way galaxy, and the universe. They were introduced to how people see stars and planets, why stars and planets cannot be seen on cloudy nights, why planets cannot be seen in the day time, and why models of the solar system might change. The reading also discussed the limitations of most models of the solar system.

- List the following: Milky Way galaxy, sun, universe, solar system, moon, and Earth.
- Ask students to order them from largest to smallest. (*The correct order is the following: universe, Milky Way galaxy, solar system, sun, Earth, and moon.*)
- Have students compare the models they drew on page 2, checking that they accounted for all three conditions described. Ask students to talk about the limitations of most models of the solar system.
- What is different about the way people see stars and planets? Why can stars and planets not be seen on cloudy nights? Why can we not we see planets during the daytime?

Introducing the Lesson

The purpose of this discussion is to get students to notice that reflection plays a role in answering the Driving Question: Can I Believe My Eyes?

- What experiences have you had in which you saw something unusual in a mirror? *(Seeing wavy images in carnival mirrors, rounded images in fisheye mirrors, upside down images in metal spoons, or distorted images in car mirrors.)* Point to the part of the consensus model that shows light bouncing off the object that is seen.
- Thinking about the experiences you just shared, does light bounce from objects in the same way? Why? *(Light does not bounce off all objects in the same way, as evidenced by the different ways that they saw reflections in different kinds of mirrors.)*

The next set of investigations will involve gathering data to help answer the question on the DQB: How does light interact differently with different objects?

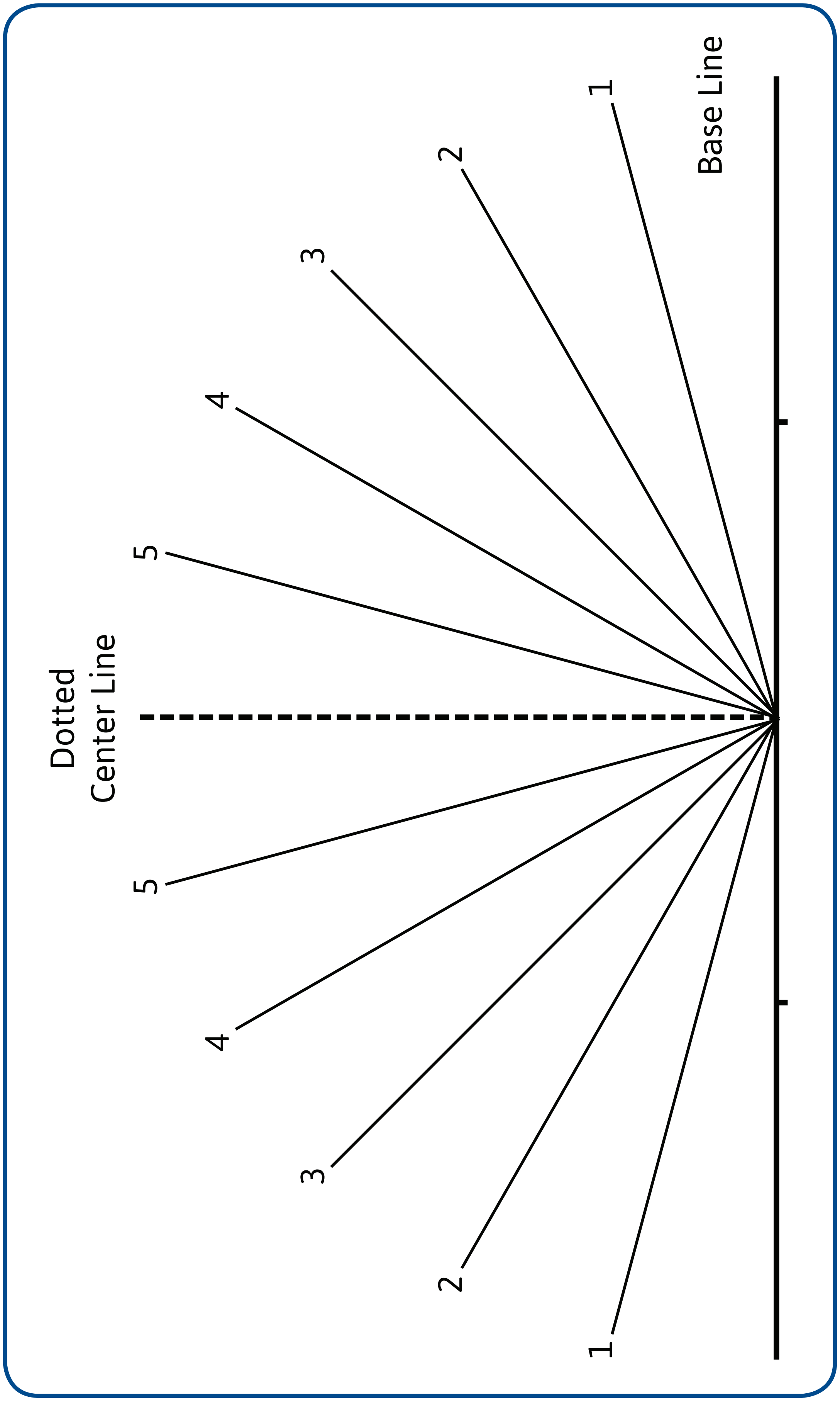
Materials – Activity 6.1

For Each Group
- (2) metersticks*
- (1) flashlight
- (1) light sensor*
- (1) mirror
- copies of "Angles" sheet*

For Each Student
- Activity Sheet 6.1
- (1) ruler*

*This item is not included in the kit.

Angles Sheet



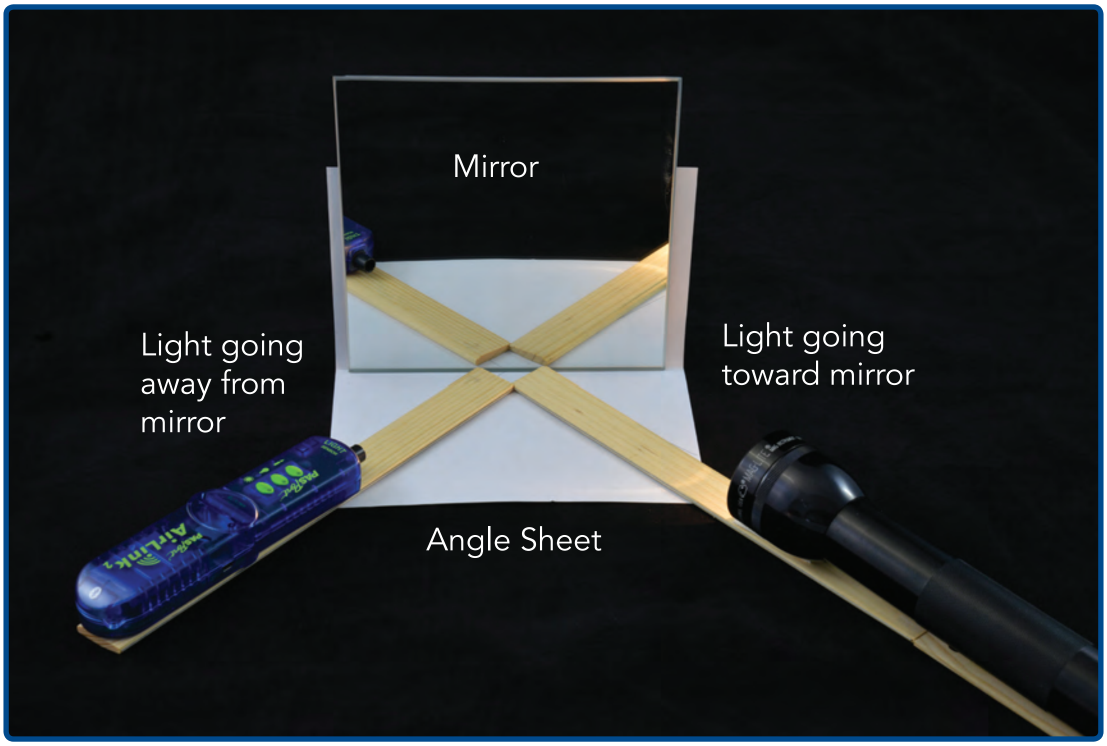
Activity 6.1 – Reflection

This investigation is intended to generate evidence about the difference between the ways light bounces off a mirror and off a wall. Use a flashlight to shine a light at an angle at a wall. Then use the same flashlight to shine a light at an angle at a mirror.

What did you observe was similar or different when the light was shined on the wall compared to when it was shined on the mirror? *(When the light bounces off the mirror, it makes a spot of light on another wall, whereas when shining the light on the wall, the spot of light is at the point where the flashlight is pointed.)*

Groups should go to their lab stations. Each group should use the setup, as shown in their books with a sheet of paper instead of a mirror, so that the orientation of the metersticks with respect to the flashlight beam can be clearly seen.

Rulers can be substituted for the metersticks, or it will suffice to put the light sensors and flashlights at the end of the lines on the Angles sheet (at a 10cm distance). Be sure that the distance from the sensor and flashlight to the paper or mirror remains constant. If there is limited wall space, science fair boards or the light boxes from Lesson 2 can be used as a backstop in place of a wall. The room does not have to be completely dark, because pattern and light sensors only measure light directly entering them; room lights do not significantly change the readings. When flashlights are taped to a ruler, they point upward if the front edge is wider than the rear edge. Place something under the rear edge, so that the light beam is parallel to the tabletop.



Instruct students to follow these procedures:

1. Students should place the meterstick with the flashlight on it so that the light shines directly at the mirror just above the dark centerline on the Angles sheet. The meterstick should be oriented along Line 1 on the Angles sheet. If the metersticks overlap each other at the vertex, they should simply pull the metersticks back a few centimeters along the line until they no longer overlap.
2. While leaving the meterstick with the flashlight fixed in its place, students should rotate the meterstick with the sensor around the point on the paper where all the lines meet to find the orientation at which the reading on the light sensor is the biggest.
3. Students should draw the orientation of the two metersticks that resulted in the maximum light meter reading on their activity sheet. Make sure students label the positions on the activity sheet. They should also record any observations they have regarding anything they may have noticed as they found the maximum light sensor reading.
4. Students should repeat Steps 1 through 3 until they have positioned the meterstick with the flashlight on it at all five positions drawn on the Angles sheet.

If you have time, practice Steps 1 through 3 as a class to prevent confusion.

This measurement procedure may be confusing to some students. In this activity, students will make five sets of data recordings, one for each position of the flashlight. In order to help students follow the procedure and record the data, it may be useful to model Steps 1 through 3 with the entire class for the first data set when the flashlight is in Position 1. Then students should practice making the measurements for the second data set with the flashlight in Position 2. The class then can reconvene to compare measurements. Once students have practiced collecting data for flashlight Positions 1 and 2, they can complete the remaining measurements for the next three flashlight positions.

Once students have completed the Data Collection/Observation section on their activity sheets, have them answer the first question in the Conclusions section in their groups, or move directly to a Pressing for Understanding discussion. Point out that as students collected the data, they recorded it in the data table, which organized the data in a particular way. Organizing data helps scientists (and students) recognize any patterns that might be there. These patterns help scientists draw conclusions that add to their knowledge of how the world works.

This discussion is very important. The students will find it difficult to recognize V patterns without this discussion.

Discussion – Pressing for Understanding

Purpose

Recognize the symmetrical V pattern in their results that is characteristic of reflection.

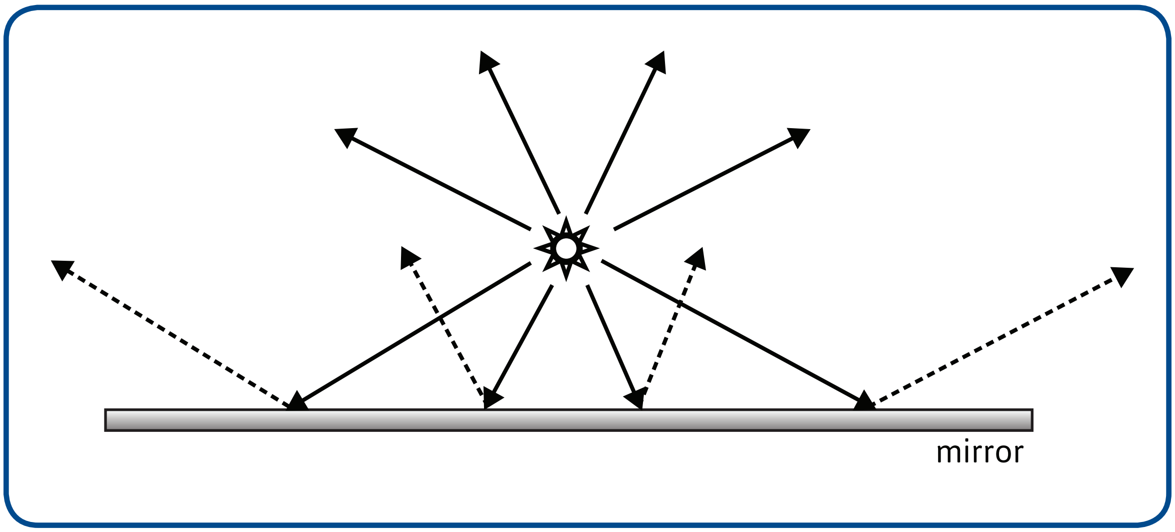
Suggested Prompts

- What shape did the metersticks make when the sensors had the highest readings? (*It had a "V" shape.*)

- How did the position of the sensor compare with the position of the flashlight when the sensors had their highest readings? (*The sensor was on the same number as the flashlight—directly opposite each other at the same angle relative to the mirror.*)
- When the sensor had the highest reading, what was the relation between the angle of the light reaching the mirror (the angle of incidence) and the angle at which the light was reflected from the mirror (the angle of reflection)? (*The angle of incidence equaled the angle of reflection. Note: Students do not need to learn these terms.*)

If students are familiar with angles, draw the angles of incidence in the model the students are drawing in their activity sheets, and draw the angles of reflection. Point out that these angles are identical. Remind students that the flashlight only helps to investigate rays that are traveling out in one direction, while the sun or a light bulb emit light in all directions. Have students work in groups to apply what they learned about reflection from this investigation.

On their activity sheets, students are asked to complete the following picture by drawing in the dotted lines shown. Look for the solid line hitting the mirror and the dotted line leaving the mirror forming a symmetrical V shape.



Materials – Activity 6.2

For Each Group

- (2) metersticks*
- (1) flashlight (preferably one that can be focused tightly)
- (1) light sensor* (a combination temperature, light, and sound sensor is shown in setup)
- photos* (a stand-alone light sensor can be used as well)
- (1) mirror
- (1) sheet of paper*

For Each Student

- Activity Sheet 6.2
- Homework 6.2

*This item is not included in the kit.

Activity 6.2 – Investigating Scattering and Reflection

As in Activity 6.1, shine a flashlight first on a mirror, then on the wall. Then ask the following questions.

- Based on what has been added to the model so far, what can you explain about how light interacts with these two objects? What can you not yet explain? *(Light reflects off a mirror at an angle opposite to the angle at which light hits it, but the model does not yet help us explain why paper is different.)*
- How can you investigate how light bounces off a nonshiny object, like a sheet of paper? *(Use the same procedure, but substitute a sheet of paper for the mirror.)*

Use Activity Sheet 6.2. Students use the same setup as in the previous investigation, but they will leave the flashlight at a single position and take readings with the sensor at all points on the opposite side. To help make comparisons, students take readings with the mirror first and then switch to a sheet of paper. Students should summarize what was observed in the last investigation with the mirror and make a prediction based on the light model about what the readings will show when the flashlight is shined on the paper.

- What do you predict the readings will be with the sheet of paper? Why? *(Students may respond that the readings will be close to zero because the paper does not reflect light or that the pattern will be the same but the numbers smaller because the paper does not reflect as well as the mirror. It is important that students give a rationale for their prediction.)*

Construct the data table for Activity Sheet 6.2 as a whole class.

After guiding students through the setup and describing the activity, take time to develop the data table together as a class. Instruct students that the column on the left in data tables is what they control (or change in a controlled manner) in the experiment, and the column on the right is for what they measure. When developing the data table, ask students what they think is important to write as they are taking measurements. Students should mention the reading on the light sensor and the position number of the light sensor. If they do not mention one of these, you should suggest it.

Instruct students to follow the procedures in their student books.

Once students have finished collecting data for both the mirror and the sheet of paper, have them work with their group members to complete the Making Sense questions at the end of the activity sheet.

When students compare the data in their two tables, check to make sure they are describing the different data patterns. With the mirror, there should be a peak (high) reading at a specific position, whereas with the paper, all the readings should be similar to one another.

In order to help students recognize the different patterns using the mirror and paper, ask students to circle the highest value for the paper and underline the lowest value for the paper. Then also circle the highest value for the mirror and underline the lowest value for the mirror. Ask students to compare the difference between the highest and lowest values for the mirror and paper. The mirror should have a large difference between the highest and lowest readings, and the paper should have a small difference.

Introducing Homework 6.2 – Scattering and Reflection – Part 1

Ask: "Based on our current model of how light helps us see, how would you explain how we see a piece of wood?" *(Light from a source bounces off the piece of wood and into our eyes where it is detected.)* An important part of the scientific modeling is identifying places the model can be further developed or improved. The homework asks students to use the model to explain how they see the piece of wood. They will use their ideas in the next period as they analyze data they collected on the paper and the mirror and develop new ideas about how light helps people see.

Materials – Activity 6.3

For the Teacher

- (1) mirror
- sandpaper
- (1) projector*
- PI: Paper Magnified
- PI: Light Hitting a Surface
- PI: Student Drawing Models
- PI: Flashlight
- PI: Flashlight Bouncing Off Wood

For Each Student

- Activity Sheet 6.3
- Reading 6.3
- Homework 6.3
- Reading 6.4

*This item is not included in the kit.

Activity 6.3 – Explaining Scattering, Reflection, and Images

Weave follow up of Homework 6.2 into today's discussion.

Discussion – Pressing for Understanding

Purpose

Make sense of the light sensor's readings.

Suggested Prompts

- What similarities or differences did you see between the sensor readings taken with the mirror and those taken with the paper? *(The readings from the mirror were very high at one specific location, while at all other locations the readings were very low. With the paper, some light was measured at all positions with only small differences between the different positions.)*
- How would you summarize the sensor readings taken with the flashlight shining on the mirror? *(They were low at all points, except for immediately opposite the light, where readings were very high.)*
- How would you describe or summarize the sensor readings taken with the flashlight shining on the paper? *(Readings are about the same at all points and only a little higher opposite the light.)*
- How did the data you collected compare with your predictions?
- Why do you think we see different patterns in the light reflected off of a mirror and the light reflected off of paper? *(Because a mirror is smooth, it reflects all the light consistently in one direction, while the paper, because it's rough, scatters light evenly in all directions. Students do not need to use the words "reflect" or "scatter.")*
- How is the surface of a mirror different than paper? *(The mirror is shiny or silvery, and the paper is smooth or white; a mirror's surface is smooth, while a paper's surface is rough, though at a very small scale.)* If students struggle to make this distinction, show PI: Paper Magnified, which shows a close-up picture of the corner of a sheet of paper.
- Given that this is what paper looks like very close up, how do you think light would bounce off this surface? *(Light would bounce off in different directions, depending on how it hit the surface of the paper.)*
- Based on what you know about the surface of a sheet of paper compared with the smooth surface of a mirror, why was the data for the mirror different from that of the paper?

Display PI: Light Hitting a Surface and PI: Student Drawing Models, which show models of light hitting a mirror and light hitting paper. Ask several students to come to the board and draw light rays as they think they will leave the mirror. Ask others to come to the board and draw light rays as they think they will leave the paper. Notice that light hitting a mirror is on the left and light hitting paper is on the right. Only the blue arrows are initially drawn.

Note: PI: Student Drawing Models shows what the students' drawing should be like.

Students should identify that light interacts differently with different surfaces. When light bounces evenly off of a very smooth surface, like a mirror, it is called reflection. When light bounces off of a rough surface like paper, it is called scattering.

- We now have some new models to explain how light behaves when it reaches objects with rough or smooth surfaces. How do these models relate to the consensus model constructed previously? *(The new models explain in greater detail what happens when light bounces off of different objects. This different behavior results in objects being seen in different ways—some surfaces create reflections, while others do not.)*
- Do the new models replace the previous model? Why? *(The new models do not replace the previous model; they just expand the detail of one part of the model—the part where light reaches an object.)*

Summarize for students that this investigation helped them think in detail about what happens when light reaches different objects but that the original model still helps explain the role of light in seeing. Explain that scientists make decisions about how much detail is needed for a model to explain a phenomenon. If they wanted to explain how people see a sheet of paper, our original consensus model meets our needs. If they want to explain why they see a mirror differently than they see a sheet of paper in terms of how light interacts with each, they need the new ideas. In general, students will work with the original model, but they should keep in mind that they might need to include the other models to explain some things.

By explicitly referring to and discussing specific examples of models' strengths and limitations, you can help students better understand these ideas. You might also talk about the importance of evaluating and revising models so the models can better overcome those limitations and meet their intended purposes. You can also refer to these ideas about advantages, limitations, evaluation, and revision in a Features of Models chart, or add them if they are not there already. For example, in PI: Student Drawing Models, students may be confused by the line that represents a light ray and apparently goes straight through the flashlight. This is because there is a limitation to the model in PI: Student Drawing Models; it cannot represent that the light from the flashlight spreads out in a three-dimensional manner, not just in one plane. The center light ray in PI: Student Drawing Models is actually reflected from the mirror toward us, so that it does not reach the flashlight.

Demonstrate that the difference between reflection and scattering is determined by the roughness of a surface by scratching the surface of an inexpensive plastic mirror with sandpaper. If time allows, demonstrate a re-creation of the procedure in Activity 6.2 to show that the scratched mirror no longer has the same high maximum that they observed with the unscratched mirror.

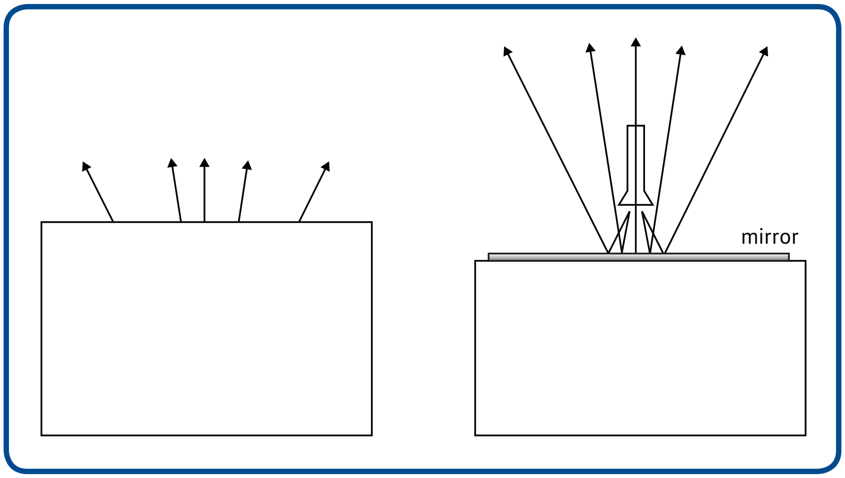
Discussion – Synthesizing

Purpose

Construct the idea that the way the surface of an object scatters or reflects light determines whether or not an image can be seen.

Hold up a mirror and sheet of paper. Ask: "Why can you see an image of yourself in the mirror but not in the paper?" *(Students should use the consensus model and the light sensor readings to explain that the way light is scattered or reflected from objects must affect whether an image can be seen or not in the object.)*

Show students only the top half of PI: Flashlight. Explain that the rays they see above the sheet of paper represent light leaving a flashlight. Direct students to the diagram showing the covered view on their activity sheet. Have students make a prediction about the position of the flashlight based on the light rays coming out by drawing it in. When they have finished drawing their predictions, compare their predictions with the person sitting next to them. Make sure students explain their drawings.



Lower the sheet of paper covering PI: Flashlight (but do not remove it completely) and reveal that there is a mirror reflecting light from the flashlight, as in the previous diagram. (Students will likely not have predicted this situation.) Call students' attention to the individual light rays. Students should notice that the angle each makes with the mirror before it hits the mirror is the same as the angle it makes with the mirror after it has been reflected. Remove the whole sheet of paper and reveal the dotted lines beneath the mirror that represent what the mind interprets based upon the light that reaches the eyes. *(Students likely thought the position of the dotted flashlight was where the flashlight was located when making their predictions.)*

Look back at Activity Sheet 6.1. The drawing students made there should look similar to the projected image (besides the dotted lines). It is as if the light rays when they are reflected look like they should be coming from a point behind the mirror. This is why when a person looks in a mirror, it looks like they are seeing objects on the other side of the mirror.

Explain that eyes are like sensors of the light rays that hit them. People can only see light that enters their eyes. This is why the mind can be fooled by a mirror—it makes it seem like the light is coming from a different place than where the light source actually is. The predictions students made were like what the mind sees when the eye receives light reflected by a mirror. Show PI: Flashlight Bouncing Off Wood. It shows the same scenario as PI: Flashlight, but with a piece of wood in place of a mirror. The diagram shows PI: Flashlight Bouncing Off Wood with paper covering the bottom half and then with the paper removed.

With the wood, it does not seem like the light rays are all coming from the same place. When scattering occurs, the eyes just see light without a pattern. They can still see brightness as a result of the light from the light source, but they do not see an image of the light source itself. This is shown on PI: iPod, where the smooth iPod shows a reflected image and the rough one only shows a bright spot.

Activity Sheet 6.3 contains a question in the Making Sense section. Depending on time, have students work on the question now, or assign it for homework.

Introducing Homework 6.3 – Scattering and Reflection – Part 2

In this homework assignment, students are asked to explain why they can see the image of a car reflected on a wet road but not a dry road.

Why do you think you can see your face reflected in a lake or pond when the surface is smooth, but you cannot when the water surface is rippled? *(Students should explain the difference in terms of light being reflected in the first situation but scattered in the second.)*

Homework may be incorporated into the next class discussion or it may be collected and first used formatively to assess students' understanding prior to proceeding with the next lesson's activities.

Wrapping Up the Lesson

Discussion – Summarizing

Purpose

Review the two ways that light can bounce off objects and connect these to the consensus model for seeing.

Suggested Prompts

- What are the two ways that light can bounce off an object? *(Two ways are reflection and scattering.)*
- How are reflecting and scattering similar and different? *(Light bounces uniformly off an object when it is reflected; light bounces randomly in many directions when it is scattered.)*
- What determines whether a surface will reflect light or scatter it? *(If the surface of the object is very smooth, the light is reflected. If the surface of the object is rough, the light is scattered.)*
- Why can a person see a reflection in a mirror, but not in wood? *(Because the mirror is smooth, it reflects light evenly, sending the pattern of the image back to our eye. The wood, because it is rough, scatters light in different directions, which bounces light back to our eye but changes the pattern so we do not see an image.)*

After the class agrees on an answer, write it down and post it near the DQB, highlighting the terms *reflection* and *scattering*. Add these ideas, in students' own words, to the Scientific Principles lists:

- Scattering occurs when light bounces off an object in all directions. This occurs when the surface of the object is rough and unpolished.
- Reflection occurs when light bounces off an object only in a certain direction. This occurs when the surface of the object is smooth and polished.
- A reflection of one object is seen in a second object only if the second object reflects light, not if it scatters it.

At the end of this lesson, projected images such as Student Drawing Model could be put in a plastic sleeve and displayed on the DQB as a visual representation of what students have learned thus far about reflecting and scattering, or any other major concept students learned. Space on the DQB may be a factor, but it is important that aesthetics and the neatness of the board do not outweigh the support provided to students when they can refer to the visual representations and be reminded of them frequently throughout the unit.

Introducing Reading 6.3 – Polishing Objects

This reading extends the relationship between the scattering or reflecting of light from an object's surface, and how people use this relationship for aesthetic and technical purposes. Project the photograph in Reading 6.3 and ask: "What do you think is this photo?" Instruct students to be ready to talk about what it means to polish and how polishing connects to scattering and reflecting light.

Introducing Reading 6.4 – Moon Phases

Reading 6.4 may be assigned now or later in the unit. See reference in Setup section of the Lesson 6 Preparation pages.

Lesson 7

Transmission of Light

PREPARATION

Teacher Background Knowledge

Transparency, Translucency

When light passes through objects such as clear glass or pure water, so that objects on the opposite side of the glass can be seen clearly, the glass and similarly clear objects are called transparent. When light passes through objects so that only a diffuse glow from the light source can be seen, they are called translucent. Examples are very murky water and sand blasted glass (often found in glass shower doors). Students may wonder how light passes through solid objects to begin with. This has to do with the characteristics of the atoms and molecules of which a substance is made and how they are arranged spatially. An explanation of this phenomenon involves quantum mechanics and is typically dealt with only in college level physics.

Translucent materials scatter light more than transparent materials, so it is difficult to distinguish a clear image. This scattering can happen as a result of a rough surface (as in sandblasted glass) or as a result of tiny particles suspended in the object (such as murky water). You may have noticed that it is possible to see more clearly through translucent glass if you place your eye very close to it—this is because the closer you are to the glass, fewer light rays get crossed. The thickness of materials can also determine whether they are transparent or translucent. If scattering occurs because of suspended particles, a thick object will scatter a lot of light, while a very thin object will look fairly transparent.

Your eye may tend to think that transparent objects transmit more light than translucent objects, but this is not necessarily the case—the difference between transparence and translucence is the degree to which light is scattered as it passes through the material, not how much light actually passes through. This is an example of how your eyes can be fooled and is another reason why measurement devices are important when determining how much light is transmitted by an object.

Transmission

When a barrier blocks the straight-line path from an object to your eye, there is typically a mix of scattering or reflection and absorption of light. For example, a black sheet of paper will absorb most of the light and scatter very little of it. At this point, students should not be expected to realize that barriers can absorb as well as scatter light. If they mention it, let them know that they are correct and that they will study absorption in the next lesson.

Students may have used the term *refract* when talking about experiences when light has been transmitted through matter. Refraction is a special type of transmission. Because the learning goals for this lesson are focused on transmission, refraction is not addressed.

Evaluating Models

There are several criteria that are useful in evaluating models, including how well the model aligns with evidence and existing scientific knowledge, and how accurately it enables the user to explain phenomena and predict new phenomena. After evaluating a scientific model on the basis of these and other criteria, scientists sometimes revise their models. A model is revised so that it better fulfills its intended purpose and takes into account the existing evidence. Revisions often make a model consistent with new experimental evidence or make it accurate for a wider range of conditions. New components and new relationships may be added to the model. Sometimes, though not often, a scientist determines during the evaluation stage that the model is beyond repair, at which point it is better to construct an entirely new model.

Using Models to Predict

Using the consensus model, students should predict that the object will not be seen, because the path of light between the object and the eye is blocked by a barrier. However, students' observations should be different from their predictions. This scenario does not agree with the model of seeing that they have already developed because it says that if a barrier is placed in the straight-line path between the object and your eye, then you cannot see it. This means that the model needs to be revised because it predicts something different from what is observed.

Most students will know in advance that the object can be seen through the transparent divider. Have the students use the model to predict anyway, because the main purpose of this activity is to emphasize how models are used to make predictions. Those predictions are then checked against observations, and if the predictions and observations do not match, then the model must be revised. Remind students, referring to the Features of Models chart, if you are keeping track of features, that models need to be consistent with related theories and existing evidence, and this consistency is important in determining what is a good model.

The Trading-Objects Activity

The purpose of exchanging objects between groups is to illustrate that it is likely for different groups to order the objects differently. Students are more likely to disagree if they have several objects with similar levels of transmission because it may be difficult to determine which transmits more light. It is also important to use at least six objects as opposed to fewer, because having more objects to order increases the chance of there being variation between groups, which is good in this activity. The rank ordering activity will be used later in the lesson to help students see the benefit of using measurement devices to provide more objective comparisons.

Creating Data Tables

Students may need practice designing data tables on their own, so do not be surprised if students are not sure where to begin. You may want to support struggling groups or ask them to talk to another group. Even if students struggle, it is important for them to do some active thinking about designing a data table on their own and recording their ideas. An important principle of data table design is that the controlled variable (in this case, the objects being placed between the light source and the sensor) is on the left, and the measured variable (the light sensor's reading) is on the right. A sample data table is shown here.

SIDE	POSITION	REPRESENTS
White side	Faces the sun	The half of the moon is lit by the sun.
Dark side	Faces away from the sun	The half of the moon is not lit by the sun.

Checking Sensors

Be sure students have sensors on the appropriate intensity setting. If the light sensor's reading without an object between the source and sensor is the same reading as when an object is in between the sensor and light source, then the sensor is likely on the wrong intensity setting.

Results of Investigations

Students should notice that the lists that they compared with their light sensors matched better than the list they made with their eyes. If this is not the case, they may have done one of the following:

- Used heterogeneous objects and measured different parts of them.
- Performed a very good job with their eyes so that both lists matched very well.
- Used a different measurement procedure.

It will not be uncommon for students to notice that, while their light sensor lists may have matched well, the values that they recorded in their data were different. Ask students to think about why they may have found different values. Likely reasons include the following:

- Differences in the brightness of their light source.
- Differences in how their light sensor was positioned relative to their light source.
- Differences in the light sensors—they may be calibrated slightly differently.
- Differences in the amount of light transmitted at various places in the object.

Representing Light Rays

Some students may ask why some light rays are reflected and others are transmitted. An appropriate response to these students would be that they are modeling what happens in the real world. The model should show that most of the light that leaves the source travels through the glass, while only some gets reflected. They could just as easily have drawn another ray to be reflected, so long as most of the rays are transmitted. It is most important to focus on *how many* rays are being reflected and transmitted, not *which* rays are being reflected or transmitted.

Reading 10.2 Alternative

Reading 10.2 addresses lunar eclipses as an application of forces and motion in a real-world context. The reading is described toward the end of Lesson 10, but may be used any time after Reading 6.4 has been completed.

Common Student Ideas

Understanding the Behavior of Light

Many students think an object looks the way it does because of the way the object is, not because of the way light interacts with it. Students believe transparent objects are those that people can see through, rather than the scientific explanation that people see through transparent objects because light can pass through the object to people's eyes. Students also may think that people cannot really see through translucent objects, but they can see a little light through them, rather than the scientific explanation that translucent objects scatter light as it passes through them. The data students collect during this activity is meant to address these alternative conceptions. After analyzing the readings from the light sensors, students should recognize that the objects with the highest light readings are the transparent objects. Why can we see through some objects but not others? The explanation is based on the evidence that more light is uniformly transmitted through transparent objects because the light readings are higher. Translucent objects still transmit light, but the light sensor readings are not as high because some light had been scattered away from the sensor.

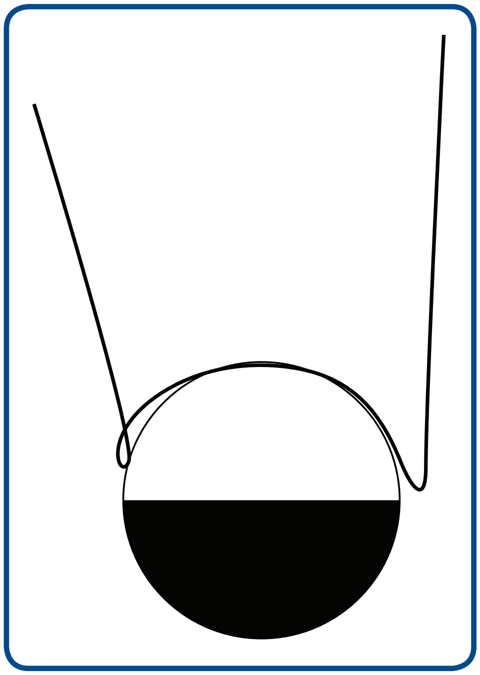
Some students may notice that no light rays are shown traveling from the wood to the eye in Position B, and they may ask why they can usually see the wood in real-life situations where a piece of wood is between their eye and the source.

A good response is to tell them that they can often see the wood because light from the source can bounce off of other nearby objects (like a table, a wall, or even their own faces!) and be redirected toward the side of the wood that is away from the light source. This light can then bounce off of the wood and travel to their eyes, making it possible to see the wood. However, when their eye is in Position B, they will not be able to see the source because no light from the source is transmitted to their eye.

Setup

Reading 6.4 Review

Before class, paint half of each Ping-Pong ball by dipping it into black paint. This is easily done by sticking a piece of masking tape to each ball, and dipping the ball into the paint while holding the masking tape. Let the paint dry while the balls hang from the tape so that the black side is face down. This will keep the paint from dripping down the white side.



When the balls are dry, puncture them with a skewer so that the skewer passes through them. The puncture holes should be along the border between the black and white halves. Leave the balls attached to the skewers.

Activity 7.2 Setup

Place items around the room, including overhead transparencies, sunglasses, CD cases, plastic wrap, and cardboard. Also include various types of paper, preferably not colored (tissue paper, notebook paper, construction paper, wax paper, or butcher paper).

Avoid prescription eyeglasses, test tubes and beakers, drinking glasses, and paper with printing on it. If students collect such objects, tell them that they will be comparing these objects later, and part of a fair comparison is using only flat objects for this activity.

Safety Guidelines

Refer to IQWST Overview.

Differentiation Opportunities

This unit does not deal with refraction, which is a special case of transmission in which light is bent as it passes through transparent objects. Refraction is the principle that underlies the behavior of lenses and prisms. It is also the reason why an object immersed in water may appear to be nearer the surface than it actually is. You may wish to have advanced students go a layer deeper and pursue study of refraction independently, although such understanding is not needed to understand the anchoring activity or answer the Driving Question. Such independent study may enable students to address other elements of the Common Core as they pursue texts of different levels of complexity, for example, or integrate information presented in varied ways (e.g., both in text and visually).

Lesson 7

Transmission of Light

TEACHING THE LESSON

Performance Expectations

Students will

- use technology (a light sensor) to measure transmitted light, evaluate the consensus model of light with respect to its ability to explain transmission, and revise the model to incorporate transmission.
- use the revised model of light to explain why it is possible to see through some objects but not others.

Building Coherence

This lesson introduces students to the second way that light can interact with objects and materials: transmission. The lesson generates evidence for revising the model from Learning Set 1 to account for transparent objects. A second focus is the importance of measurement devices and data organization.

Timeframe

2 Class Periods

Overview

Activity 7.1
Use the light boxes to recognize that the current consensus model leads to incorrect predictions because it does not account for transparent objects.

Activity 7.2
Rank order objects that transmit light according to how much light they transmit, first with their eyes and then with the light sensors.

Activity 7.3
Revise the consensus model to incorporate both transmission and scattering or reflection.

Introducing the Lesson

In the last investigation, students investigated two different ways that light can bounce from objects—scattering and reflection. Ask students to summarize the difference between scattering and reflection. *(When light is reflected off a smooth surface, it bounces evenly off the surface, while when it scatters off a rough surface, it bounces off in all directions.)*

If light did not bounce off objects or did not scatter or reflect, how would that affect how people see objects? (*If light did not bounce off of objects, people would not be able to see them, as the eyes sense the light that is scattered or reflected.*)

Reading 6.3 Follow Up

Choose and review one of the questions from the reading to further support students in making sense of reflecting and scattering and when they matter to people outside of science class.

- Look back at the responses you gave to the questions at the end of the reading. What does the fact that people use shoe polish to make shoes more reflective tell you about the surface of leather? *(Leather normally must be somewhat rough, because it is not reflective, but the polish must do something to make it smoother and reflect light more evenly.)*
- The reading points out that even polished objects still scatter some light—nothing can reflect perfectly. Why do you think this is? *(Polishing makes surfaces smooth, but no surface is perfectly smooth, so it will still scatter some light. Students may say that there is roughness that cannot be seen or is microscopic.)*

Materials – Warm-Up Activity	
For Each Pair	***For Each Student***
• prepared ping-pong ball*	• Reading 6.4

*This item is not included in the kit.

Warm-Up Activity

Note: This is actually more than a discussion of a reading—it is a full-fledged activity. It should be done the day after assigning Reading 6.4, but note that Reading 6.4 need not be done at the end of Lesson 6; it can be done anytime during Learning Set 2.

The purpose of this activity is to help students see that the phases of the moon are the result of the relative positions of the sun, earth, and moon, and the phases do not involve shadows.

There is no intent to account for the moon's rotation in this activity, because it is unimportant in understanding the moon's phases. If it arises as a question, discussion will likely complicate current learning goals and confuse many students. Students who raise questions about this could be directed to investigate independently.

Distribute the skewered Ping-Pong balls to pairs of students. Have a member of each pair hold the skewered ball at arm's length, straight in front of him or her, with the ball oriented so that the white half is to the left and the black half to the right. Have students draw what they see (without drawing the skewer) on their activity sheet. Have the other member do the same. Students should draw a circle, the left half white and the right half black.

Ask: "If you were Earth, the Ping-Pong ball were the moon, and the white half of the Ping-Pong ball were the side of the moon illuminated by the sun while the black half were the dark side, where would the sun be located? *(The sun would be to the left on the side of the moon that is illuminated or white in the model.)*

Now have students move their arms, still outstretched, 45° to the left, twisting the skewer in your hand a bit, so that the white half of the ball still points in the same direction—to the left. Tell students that while the moon has moved a bit, neither Earth nor the sun has moved; the sun is still to the left. That is why the white side of the moon still has to face left even though the moon has moved.

Have students again draw what they see. They should draw a circle with a white crescent on the left. Ask students if the white shape they see is familiar to them. Repeat this again, this time with the moon being held to the students' left, with the white (illuminated) half still facing left, therefore away from them. The students should see and draw a black circle.

Repeat this two more times, once with the students' arms 45° to the right of the original position of the moon, and once completely to their right. In each case, make sure the white half of the Ping-Pong ball remains facing in the same direction—to the left. When the ball is 45° to the right of the original position, students should see and draw a gibbous moon, and when it is to their right, they should draw a completely white circle.

Now have students look at Reading 6.4 and give names to the various shapes they drew. The names, from the leftmost position to the right are as follows: new moon, waning crescent, last quarter, waning gibbous, and full moon.

Ask: "If the Ping-Pong ball were directly behind you, with its white half still facing in the same direction, and then you turned to face the ball, what would you see?" *(You would see the first quarter moon, with the right side white and the left side black.)*

Acting It Out

Choose three volunteers. Have one sit on a swivel chair with enough space around it so that a student can walk around it easily. Have one volunteer sit on the chair and tell the class that this student is going to pretend he or she is the earth. Darken the room and have this student slowly turn around in the chair. It should take about 10 seconds for Earth to complete a rotation. Have a second volunteer stand far away from Earth but point the lit flashlight at the earth. Tell the class that the second student is the sun.

- Why is the flashlight a poor simulation of the sun? *(The sun emits light in all directions, while the flashlight emits light only in one general direction.)*
- Which side of Earth is in daytime and which side is in nighttime? *(The side that faces the sun is in daytime because it is illuminated by the sun.)*
- How long does daytime or nighttime last? (*It lasts half the time it takes for Earth to complete revolution around its axis.*)
- What causes it to be dark during the night even though the sun is still shining? *(The side of Earth facing the sun blocks the sun's rays, so no sunlight reaches the other side.)*

Have the third volunteer walk slowly around the earth. The student should walk in the same direction in which Earth is spinning. Tell the class that this student is the moon. This student should walk very slowly, much slower than Earth. The earth should complete many revolutions before the moon completes one.

- Is the moon more often in the night sky or in the day sky? Why do we always think of the moon as being in the sky during the night and not during the day? *(The moon is just as often in the day sky as it is in the night sky. We associate the moon with the night because it is much more visible then, because the sky is dark and the moon stands out. During the day, the sky is bright and it is much harder to see the moon, so we usually do not notice it.)*

- Why does the moon rise a bit later every day? *(Because the moon advances a bit in its orbit every day, Earth has to spin a little bit more every day for the moon to be above the horizon.)*
- Where is the moon located during the new moon, the full moon, the waxing gibbous moon, the waning crescent moon, and the first quarter? *(In each case, have a student locate the moon where it should be. Point out that it makes no difference in which position Earth is oriented. The phase of the moon does not depend on the orientation of Earth. All the orientation of Earth determines is whether people on it are in day or night and what they can see, and therefore, whether they will be able to see the moon at all or not.)*

☑ Students should explain that scattering occurs when light hits an object with an uneven or rough surface and bounces off in a variety of directions; reflection occurs when light bounces off of a smooth surface in a uniform direction. Students may say that they can see images of themselves in an object that reflects light but not in one that scatters light.

Materials – Activity 7.1

For Each Group

- light boxes used in Lesson 2*
- (1) opaque divider*
- (1) clear divider* (e.g., overhead transparency cut to fit the light boxes)

For Each Student

- Activity Sheet 7.1

*This item is not included in the kit.

Activity 7.1 – Evaluating the Light Model

Have students look at the consensus model of light that they constructed as a class. One of the important parts of the model is that there is an unblocked path between the object and the eyes. Ask students to think of situations in which the path is blocked by something but you can still see the object. Students may respond that they can still see the object when there is something made of glass such as a window or water, as in a fish tank blocking the path. Distribute the light boxes that students worked with in Lesson 2.

Have students place the opaque divider in the light box, open the flap, and look through the eyehole. Distribute Activity Sheet 7.1 and have students draw a version of the consensus model that explains why the divider has the effect it does on what they see.

Have students replace the opaque divider with a clear divider (such as a transparency cut to fit the light box). Have students use the ideas of the consensus model to predict whether they will see the object. Then students should look through the eyehole. When they have done so, have them record their ideas on the activity sheet about whether the current model explains that happened. Ask: "How does the current model of how light helps people see explain or not explain what was observed in the light box?" (*The model currently would predict that they could not see the object with something blocking the path between the object and eye. Given that they saw the object through the divider, the model is not consistent with the evidence and needs to be revised.*)

In your questions and the students' answers, use the terms *explain*, *predict*, *evaluate*, and *revise*, as well as the various evaluation criteria. These are the terms that describe the things that are done with models. Refer to your class' Features of Models chart, if you have one, when mentioning these terms.

Based on students' evaluations of the model in relation to the evidence, students should have concluded that the current model does not account for why they can see through some dividers and not others. Given the new data, students should recognize that the model will need to be revised.

Have students complete the Revise section on Activity Sheet 7.1 based on their new ideas. Tell students that they do not need to worry about being 100% sure of the answer—this is an opportunity to start thinking about a revised model.

Note: Students should be expected to struggle with this section, because they do not have information or evidence to explain why light is transmitted, reflected, or absorbed by different materials, so it is not important for students to get a correct answer right now. This question will prompt students to think about what changes should be made to the model.

Make sure students understand that the question is why light can travel through a piece of transparent material. Explain that when light passes through an object, scientists refer to it as transmission. In the next investigation, students will investigate transmission of light through objects so they can revise the model and explain why some objects are more easily seen through than others.

Read with the students the Making Sense section of the activity sheet.

Remind students that models are improved as they are revised, so that they can explain and predict more things. Scientists evaluate and revise their models all the time, as they gather new data and want the model to account for the new data. Like scientists, students will often gather data that their models cannot yet explain, and revise their model to account for them.

Note: In order to accurately predict what students see using their models, students need to gather evidence for how much light passes through everyday objects. In the next activity, students will explore the amount of light transmitted by objects around them.

Materials – Activity 7.2

For the Teacher
- transparent/translucent materials*

For Each Group
- (1) flashlight or other light source
- (1) light sensor*
- tape* (to secure lab setup)
- (1) book* (or other object to elevate the flashlight and sensor above the tabletop)

For Each Student
- Activity Sheet 7.2
- Homework 7.2

*This item is not included in the kit.

Activity 7.2 – Measuring Light Transmission

Hold up three materials: a transparency, a translucent piece of tissue paper, and an opaque piece of paper. Hold each in front of your hand to demonstrate what can be seen through each.

- Ask: "Why do you think there is a difference in what we can see through each of these objects?" *(Different amounts of light are transmitted through each material that reaches our eyes.)*
- What data might we collect to investigate how light is transmitted through different materials?

  In groups, have students find six objects in the room that transmit light.

- How do you think you can tell if an object is transmitting light? *(We will be able to see through the object. Students may or may not use the terms translucent and transparent.)*

Remind students that they can also hold objects up to the light to see if they can see the light through the object. Model this by having students hold a sheet of paper up to the ceiling lights, so that everyone understands how they can identify objects that transmit light even if the objects are not completely clear.

- Some objects that transmit very little light (such as a piece of a cardboard box) will not seem to do so when viewed with the naked eye, but this light may be detectable by the sensor. If students are not sure whether a particular object transmits light, encourage them to include it on their lists.
- Students will be using the objects they collect to do an experiment in which they use a light sensor to measure the intensity of transmitted light. It is essential that the object that students use is nearly flat, because curved objects may focus light, making it seem that there is more light reaching the light sensor than leaving the source. It is also important that the objects are as homogenous as possible to ensure that multiple groups will get the same measurements.

Once students have gathered objects, have them order the objects, from those that transmit the most light to those that transmit the least light, and record findings on Activity Sheet 7.2. Once groups have ordered their objects, have them trade objects (but not their lists) with another group. Each group should order the new set of objects in the same way, and record the second list on the activity sheet.

When students have ordered both sets of objects, have them compare the lists with the lists made by the other group with which they traded. Have students draw a data table to record data for this investigation.

Have one or more groups share their data table with the class by drawing it on the board. Discuss the options students have presented (if different ideas are presented) and decide which kind of table all students should use during the activity.

Once the data table is constructed, students should position a light sensor a few centimeters away from a light source. The distance should be large enough that their largest object can fit between the source and sensor. Both the flashlight and light sensor should be placed on a book or other object to elevate them above the tabletop, and the entire setup should be secured so that nothing can move. It is important that neither the source nor the sensor should be moved during the course of the experiment. Students should first record a control measurement for the amount of light hitting the sensor when there is no object between the light source and the sensor. They should then record a measurement from the light sensor for each of their objects.

When students have collected data for their set of objects, have them use the sensor readings to order the objects from those that transmit the most light to those that transmit the least.

When students have ordered the objects based on the sensor readings, have them trade the objects with the same group as before. Have students record the measurements of transmitted light for each object in a similar data table. Then create another ordered list for the second set of objects based on the sensor readings.

It is not important for students to agree on the numerical value of transmitted light for each object. Different groups will measure different numerical values based upon factors such as the following: the distance between the flashlight and their sensors, ambient light from the room, and different parts of the same object measured. What is important is for students to focus on the order of the objects.

Interpreting Our Data

When students have finished the second list, have them compare the lists of measurements they made with the group with which they traded. Have students complete the activity sheets.

- In looking at the lists the other group made for the same objects, which lists matched up better—the lists made with your eyes or the lists made using the light sensors? *(In general, the lists made with the sensors matched better.)*
- Why do you think one list matched better than the other? *(The sensors are more consistent or accurate than people who see things differently or might make mistakes; the sensors provide a numerical reading for the transmitted light, while people can only give more general descriptions.)*
- What are some reasons why measurement devices were useful in this investigation? *(Students may respond that the measurement devices helped them order the lists in more similar ways, make more accurate comparisons, or provide evidence that their original rankings were accurate or inaccurate.)*

Discussion – Summarizing

Purpose

Establish the value of measurement devices in science.

Suggested Prompt

- Using the ideas you recorded on the activity sheet, why do you think it is often a good idea to use measurement devices in scientific investigations? *(Measurement devices are important in this investigation because they help compare the transmission of light between objects that are too similar for eyes to distinguish. In some cases, measurement devices may have revealed that an object was transmitting light when they could not see the transmitted light with their eyes. The measurement devices also helped to resolve differences between the lists that students made with their eyes. In much of science, measurement devices can extend the senses to help people make more detailed comparisons.)*

Discussion – Pressing for Understanding

Purpose

Use evidence to explain why we can see through some objects and not others.

Have one group display their list of objects and transmitted light readings on the board.

Suggested Prompts

- Which of these objects can be seen through, and which cannot? *(It is important that students agree on the categorization. Put a check mark or star next to each object that could be seen through.)*
- How do the measurements of the amount of light transmitted by the objects they could see through compare to those of the objects that they could not see through? *(The readings in the can-see-through group are higher than the readings in the cannot-see-through group.)*
- How can the model for seeing be used to explain the pattern that objects that can be seen through have higher light sensor readings? *(Light still travels straight from the object being seen through a transparent object to my eyes.)*

Introducing Homework 7.2 – Transmission of Light – Part 1

Students are asked to look around their homes and list both measuring devices they encounter regularly and objects in their everyday lives that transmit light.

Homework Follow Up

The first goal is to help students realize that they use measuring devices all the time, although they might not have thought of them as measuring devices. The second point is for students to realize that they are surrounded by transparent and translucent objects.

- What were some of the measurement devices you found around your home, and for what are they used?
- What were some of the objects or devices you found around your home that use transmission of light? How do they use it?

Materials – Activity 7.3

For the Teacher

- (1) projector*
- PI: Consensus Model

For Each Student

- Activity Sheet 7.3
- Reading 7.3
- Homework 7.3

*This item is not included in the kit.

Activity 7.3 – Revising the Light Model

In Learning Set 1, the consensus model focused on how light travels from an object to the eye. According to the model, when light reaches an object, it bounces off of it. With Lessons 6 and 8, this activity focuses on revising the model to account for different ways in which light interacts with an object.

Students have gathered data that provides evidence that when light hits an object, it can either be transmitted or bounced off the object. If light bounces, it can be either reflected or scattered. The current model does not account for these ideas, so it needs to be revised. The new model must account for two ideas: (1) to see an object, some light must be scattered or reflected to the eye, and (2) if people can see through an object, some light must be transmitted through it.

Although the new model will look similar to the old one, all objects will no longer be the same. It is necessary to know more about the object in the model to explain what happens when light hits it. Have students record predictions on Activity Sheet 7.3 and then share their predictions with a peer.

Have two or three students draw their predictions from Activity Sheet 7.3 to show how light should behave when reaching a sheet of clear glass.

Look at the different predictions represented on the board. Which features are similar in each of the models? During the discussion, draw a new consensus model, using students' ideas to justify the drawing. In this way, it should be clear to the students that the new model is based on ideas that they raised. The new consensus model should look similar to PI: Consensus Model.

For clarity in PI: Consensus Model, which shows what the model should look like for several types of objects, the light rays that do not hit the object are de-emphasized by being shown in gray.

In the projected image, Person A will be able to see both the glass and Person B, because light that is scattered by the glass travels to his or her eye and light that is transmitted through the glass is scattered by Person B, which is transmitted through the glass again and back to Person A's eye. Person A can also see the light source directly and perhaps a reflection of it in the glass.

What will Person B see? *(Person B will also be able to see the glass and Person A, for the same reasons. Person B will also be able to see the light source through the glass.)*

Repeat the same process for students' predictions from Activity Sheet 7.3; however, this time answering the question "How should light behave when reaching a piece of wood?"

Who will see light from the light source: Person A, Person B, or both? Will they see the light directly or indirectly? Why? (*Only Person A will see light from the source, both scattered by the wood and directly from the source. Person B will not see light from the source, as it is blocked by the wood.*)

Connect to Lesson 6 and see if students understand that light scattered from objects can still be seen. The wood can be seen, so light must be bouncing back to the eyes. The light is scattered back to the eyes. Light is not being reflected back to the eyes because a mirror image is not being seen from the wood. Students may think that the light sits on the wood, but according to their model, light must travel from the object to the eye.

Have students look again at the revised model from Activity Sheet 7.1. Have groups work together to draw a version of the consensus model that predicts both the path of light when they can see a light source through a piece of paper, and the path of light when they can see the paper itself. Have one or more groups explain how their drawing shows that a piece of paper can be both seen and seen through.

Add to the list of Scientific Principles the following: Some objects are transparent and let light pass through them.

Introducing Homework 7.3 – Transmission of Light – Part 2

Students are asked to draw what happens to light rays from a flashlight as the rays strike a piece of reflective glass or a piece of paper and to explain why it is easier to see dirty windows than clean ones. In order to generate this explanation, students need to connect the idea of light scattering from Lesson 6 and light transmission Lesson 7. This homework can serve as an assessment of student understanding of reflection, scattering, and transmission—either formatively or summatively—thus may be woven into the next class discussion as appropriate.

Introducing Reading 7.3 – Using Light in Optical Fibers

This reading explores the uses of fiber optic cables, which rely on transmission and reflection of light to carry light signals through a bendable cable. By sending signals with light rather than electric currents, fiber optic cables are more efficient, can transmit information faster, and are safer than cables that carry electric signals.

Option 1

Distribute a variety of clear plastic items for students to view (bottle, CD case, and plastic wrap). How is it possible that we see things through these objects, even while they block the path of light, and see the object itself at the same time?

Explain that the reading today will help students learn more about the way clear plastic and glass interact with light using a technology called optical fibers. For the next class, students should come ready to describe an example of how an important technology required inventors to understand how light is transmitted and reflected.

Option 2

Look at the photograph at the beginning of Reading 7.3. What other objects work in the same way the lamp does? How do people use light to work the way they do?

Explain that the reading today will help students learn more about how the technology in the lamp, called optical fibers, is used for different purposes. For the next class, students should come ready to describe an example of how an important technology required inventors to understand how light is transmitted and reflected.

Wrapping Up the Lesson

- How is the consensus model different from the model we had at the beginning of the lesson? What strengths does the revised model have over the previous one? *(The new model accounts for light that also travels through objects. This is now a stronger model because it can explain more situations.)*
- What questions from the Driving Question Board can we answer now? *(One question that can be answered now is "Why can I see through some objects but not others?")*

Lesson 8

Absorption of Light

PREPARATION

Teacher Background Knowledge

Absorption

The topic of this lesson is *absorption*, but do not introduce the term until students have had an opportunity to grapple with the concept first. Later in the lesson, students will examine a phenomenon in which light is used to heat water and deduce that the light must have been absorbed by the water in order to heat up.

The Radiometer and Other Quick-to-Demonstrate Phenomena

Students are likely to be curious about how the radiometer works. The important aspect of the radiometer for this lesson is that it rotates when light is shined on it, and it does not rotate when the light is off.

Light Can Make Things Happen

Having students list items or scenarios in which shining light makes something happen is to elicit prior knowledge and to connect classroom activities to their daily lives. Possible student responses include the following: solar-powered devices, such as calculators or vehicles; glow-in-the-dark materials; a magnifying glass used to start a spark or burn objects; sunburns; and light used to heat something, like food. It is not necessary to demonstrate all of these, but demonstrating one or two is helpful. One demonstration should be using light to heat something, as that will be the focus of the investigation.

Transitioning to the Next Investigation

The goal of this whole-class discussion is to help students realize that they will need to measure

- how much light was reflected.
- how much is transmitted.
- the temperature of the water in the beakers.

If they have trouble coming up with these, ask them to think about one aspect at a time:

- What are the ways light can interact with objects and materials?
- How can they measure the amount of reflected light?
- How can they measure the amount of transmitted light?
- How can they measure how much something has heated?

The evidence that students will collect is that more light is absorbed by the dark water (because less is reflected and transmitted), and less light is absorbed by the clear water (because more is reflected and transmitted). They can conclude that when more light is absorbed, the water heats up faster. This, however, does not explain how the absorbed light heats up water. That question will be examined in the IQWST PS2 unit. For now, it is appropriate for students to recognize the pattern in the data that indicates that the amount of light absorbed by the water affects how fast the water heats up.

Sample Data

Sample data were obtained using the experimental setup shown and a 100W light bulb.

VARIABLE	CLEAR WATER	DYED WATER
Amount of reflected light	1571lux	765lux
Amount of transmitted light	5248.7lux	3543.2lux
Starting temperature	22.8°C	23.1°C
Final temperature (after 30 minutes)	44.7°C	48.7°C

The temperature of the water will not continue to increase. It will remain constant when the rate of heat transferred to the water from the bulb is equal to the rate of heat loss from the water to the surroundings. For the graph shown, the colored water seems to be reaching an equilibrium temperature of about 52°C, and the clear water seems to have an equilibrium temperature of about 48°C.

Mathematical Models

There are many different kinds of models. In the unit, until now, all the models used have been either drawn (the various versions of the consensus model) or in material form (students' initial models of light and the light boxes). Models can also be in the form of a mathematical relationship. The equation is a model—it is a representation of what happens to light when it hits an object, and it allows us to explain and predict phenomena that involve light and matter. A physicist would say that the equation models a law of conservation—what you have before equals what you have afterward.

The Model of the Flashlight

A limitation of this model is that it shows only a small number of rays leaving the flashlight. To accurately describe light, the model should actually show trillions and trillions of rays coming out of the flashlight, even for a very weak light source. Clearly, it is impossible to draw a large number of rays in a model and still be able to distinguish between them. This limitation of this model can create the impression that only one ray is absorbed. This is not correct. The intention of the model is to show only a small fraction of the total number of rays is absorbed. So what is important in this model is not the actual number of rays shown, but the percent of the total number of rays being transmitted, reflected, or absorbed.

Comparing Models

Different models have different advantages and weaknesses. The conservation equation and the drawing of light reaching a piece of glass are both representations of the same thing, but they emphasize and ignore different aspects of the phenomenon.

The equation is purely quantitative—it easily allows you to explain and predict intensities of light. It is also very general—it does not fit just one situation but is applicable to every situation in which light and matter are involved. On the other hand, it says nothing about any particular situation, such as where the light source is located, in which direction the light is propagating, and what type of object lies in the light's path.

While the drawn model shows features that are characteristic of particular situations, it is useful only for those situations and not for others that involve different materials or different light sources. It is more qualitative than quantitative—it lets us know what is happening to the light but cannot represent accurately the different intensities of light that are involved.

This does not mean that one model is better than the other. They are both useful, and when used together, they provide a much more complete representation of the phenomenon than either can on its own.

Solar Cooker

A solar cooker uses a mirror to reflect light from the sun toward opaque food. In this device, the mirror reflects most of the light that hits it (absorption and transmission are not desirable—the device would not work if paper were substituted for the mirror) toward the food. When light hits the food, most of it is absorbed, which causes the food to heat. The solar cooker works best for foods like hot dogs, but would not work well for a potato wrapped in foil. Hot dogs will absorb most of the light (reflecting and transmitting very little), and potatoes wrapped in foil will reflect most of the light (absorbing and transmitting very little).

Solar-Powered Device

A solar-powered device generates electricity when light hits it. To do this, it must absorb light. Solar-powered devices typically use a photocell that looks like charcoal gray material. Notice that this material does not look very reflective and clearly does not transmit much light. It is important for photocells to absorb as much light as possible, but they also must be covered with a protective coating. A great deal of effort is put into finding materials to coat the photocell that reflect very little light and transmit nearly all of it—this maximizes the amount of light from the sun that reaches the photocell and can be absorbed to generate electricity.

Setup

Activity 8.2

The demonstration apparatus for this activity should be assembled before class. One beaker contains clear water and the other contains water with food coloring. Fill one beaker with 25mL of water, and fill another beaker with 10mL of water and 5mL blue food coloring, 5mL green food coloring, and 5mL red food coloring.

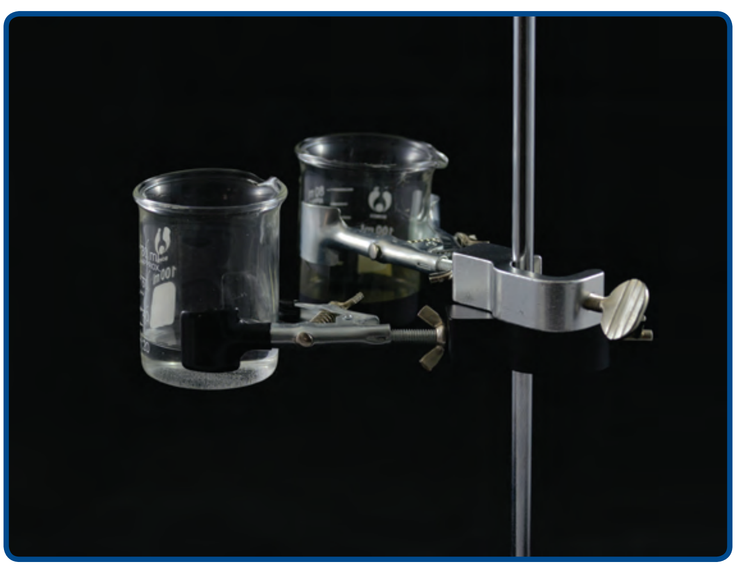
Demonstration Procedure

1. Assemble the apparatus.

    - Use two clamps to attach the empty beakers to a ring stand. Since one clamp must be positioned higher on the ring stand than the other, be sure that the clamps hold the beakers in different places so that the beakers will be at the same height.
    - Attach a ring or horizontal bar to the ring stand, so that the bulb holder can hang from it.
    - Screw the 100W halogen flood lamp into the hanging bulb holder, and hang the holder from the ring or horizontal bar so that the 100W halogen flood lamp is about 10–12cm above the beakers. To be sure that both beakers are completely within the light from the flood lamp, position the light sensor beneath each beaker, take a reading, and adjust the beakers until the sensor reading under each beaker is roughly equal.

    Note: Use one bulb to illuminate both beakers so that students are convinced that the same amount of light is hitting both beakers. If the beakers are not equidistant from the bulb, it is better to err on the side of placing the colored water closer to ensure that the results make sense.

2. Once the apparatus is set up, fill two 100mL beakers: one beaker with 25mL of water and the other with 10mL water, 5mL blue food coloring, 5mL green food coloring, and 5mL red food coloring. All three food colors are important, to absorb as much light as possible.



Safety Guidelines

Refer to IQWST Overview.

Differentiation Opportunities

Students might investigate alternative forms of energy or other uses of solar energy, prompted by the readings in this lesson. Such a research project would enable connections to other elements of the Common Core as applicable to science.

Lesson 8

Absorption of Light

TEACHING THE LESSON

Performance Expectations

Students will

- use data to explain ways in which scattering, reflection, transmission, or absorption of light cause changes in objects (e.g., amount of light absorbed and temperature increase).
- use the consensus model of light to explain the possible interactions that occur when light hits objects and materials.

Building Coherence

Students revisit reflection and transmission, and examine a third way light interacts with objects and materials: It can be absorbed. Students use the consensus model to explain how the amount of reflected, transmitted, and absorbed light is related, and to predict what they will see when light hits an object that reflects, transmits, and absorbs light.

Timeframe

2 Class Periods

Overview

Activity 8.1
Examine phenomena and share experiences in which light makes something happen.

Activity 8.2
Collect and interpret data from a demonstration in which light heats two beakers of clear and colored water.

Activity 8.3
Use the consensus model to explain the results of the demonstration. Revise their models to account for reflection, transmission, and absorption to explain what they see when light interacts with an object.

Activity 8.4
Revisit phenomena to explain how reflection, transmission, and absorption are involved in designing devices that use light to make things happen.

Reading Follow Up

Ask: "How did the technologies described in the reading require their inventors to understand the transmission and reflection of light?" Have students describe what they learned. What did you learn about how television in the past is different from television today?

Throughout IQWST, whenever you request students to ask a family member a question or to try something at home, be sure that you encourage those activities and follow up the activities in class, so that students have an opportunity to share what they discovered; doing so enables family members to become partners in learning.

Introducing the Lesson

Ask a couple of volunteers to share the models they made showing how light interacts with sunglasses and rice paper from Homework 7.3. This was a difficult task, so make sure that students know it is OK not to be 100% sure about their models. One reason to share and talk about ideas is so that the ideas can be revised and developed further. If students have errors, work together to revise. Prompt students with questions that make them think about the evidence they learned in the previous investigations.

The purpose of the following discussion is to remind students what they have learned and to check for understanding.

Use students' drawings to answer the following questions that review what has been learned so far:

- Where do you see light being scattered in the models? How do you know? (*The tissue paper shows scattering, because the rays bounce off of the paper in random directions.*)
- Which of the models shows more transmitted light? (*Answers may vary, but the model with more light rays going through the glass or paper is the one that shows more.)*
- In which of the models would you be able to see an image of the flashlight? How do you know? (*You can see an image of the flashlight in the glass, because it reflects the light rather than scattering it, which makes it seem like the light rays are coming from a point on the opposite side of the glass.*)
- For which model will it be easier to see the flashlight if your eye is on the other side of the paper or glass? Why do you think so? (*The model showing the most transmitted light rays will be easier, because more light from the object can hit your eye.*)

Have students look back at the Driving Question Board and notice the ways in which they have been improving the consensus model to include the different ways that light can interact with different materials. As they have refined the model, they have been able to answer more of the questions that were asked at the beginning and can think in new ways about the Driving Question.

Materials – Activity 8.1

For the Teacher

- (1) radiometer
- (2–3) light-related phenomena*
- time-lapse video of heliotropism*
- (1) solar-powered calculator*
- magnifying glass
- light-sensitive paper

For Each Student

- Activity Sheet 8.1

*This item is not included in the kit.

Activity 8.1 – Light Makes Things Happen

Shine a flashlight on the radiometer until it begins to spin, and turn the light off until it stops spinning or at least slows down dramatically. Do this several times to establish for the students that the radiometer spins quickly when light from the flashlight reaches it and stops or slows down when the flashlight is not shining on it. Ask: "What do you think might be going on here?"

In pairs, students use Activity Sheet 8.1 to list other instances in which shining light on an object can make something happen. After students have talked about phenomena, show them other examples in which light makes things happen. Examples may include the following: a time-lapse video of heliotropism in a plant, a solar-powered calculator, burning paper with a magnifying glass, and light-sensitive paper.

The next investigation is designed to help figure out *how* light interacts with objects and materials to make things happen. Students have collected evidence to show that light is transmitted through objects, and light is reflected or scattered off objects. Now they will investigate whether these are the only ways light interacts with objects. To gather data, students investigate what happens when light shines on dark and clear objects.

Materials – Activity 8.2

For the Teacher

- (2) temperature probes, light probes, and sensor interface*
- (1) 100W halogen flood lamp with hanging bulb holder
- (1) ring stand
- (1) clamp to hold the light bulb holder
- food coloring (red, blue, and green)
- (2) 100mL beakers
- (2) clamps to hold beakers

For Each Student

- Reading 8.2
- Activity Sheet 8.2
- Homework 8.2

*This item is not included in the kit.

Activity 8.2 – Investigating Heating by Light

Light can bounce off a material or be transmitted through it. Ask: "How do you think the food coloring will affect the ways in which light interacts with the water?" Explain that a familiar way in which light makes something happen is when sunlight shining on a surface makes the surface feel warm. What data can be gathered to investigate why sunlight feels warm? What measurements can be taken, and how can the data be organized?

On the board, develop a data table that will be used to track measurements. Predict which will have a greater increase in temperature: clear water or colored water? Explain your ideas.

1. Assemble the apparatus.
2. Position the light sensor so that it measures the amount of light transmitted by the clear water, as shown. Turn on the light briefly to take the measurement, and have a student record the measurement on the board. Do the same thing for the colored water.
3. Now, use the light sensor to measure the amount of light reflected by the water in both beakers, as shown. Turn off the light immediately after these measurements have been taken.
4. Use two temperature probes, one in each beaker, as shown.
5. With the light off, begin data collection on both probes with the sensor interface simultaneously. Have a student record the initial temperatures in the data table.
6. Let the light shine on the beakers for 20 minutes.
7. During this time, look at Reading 8.2 with students, perhaps taking the opportunity to model active reading for students. Both Reading 8.2 and Activity 8.2 deal with using light to heat water.
8. After 20 minutes, record the temperature on the two probes.

(Optional) Connect the devices to a computer equipped with software that can import the data, and merge the data sets to create a graph with overlapping date and time. If you have the ability to do this and are able to show the graph, students should be directed to notice that both lines started at the same point on the left and spread out as they go to the right, with the green line always on top. This is because the temperature of the colored water rises more than the temperature of the clear water.

After data have been gathered, instruct the class to copy the data table from the board into their student books and work in their small groups to answer the questions in the Making Sense section of Activity Sheet 8.2.

Discussion – Pressing for Understanding

Purpose

Determine that more light was absorbed by the colored water.

Suggested Prompts

- How does the amount of light that was reflected and transmitted by each beaker of water compare with the amount of light that hit them? *(More light hit each beaker* *than was reflected and transmitted [i.e., some is missing], but more light was unaccounted for with the colored water than with the clear—less light was reflected and transmitted by the colored water than by the clear water.)*

- How does the amount of reflected light in the colored water compare to the clear water? *(The colored water reflected less light than the clear water.)*
- How does the amount of transmitted light in the colored water compare to the clear water? *(The colored water transmitted less light than the clear water.)*
- How does the amount of light hitting the colored water compare to the light hitting the clear water? *(The same amount of light was hitting the clear water and colored water because they were under the same light bulb.)*
- How does the amount of missing light, light that was neither transmitted nor reflected, compare between the two beakers? *(More light was missing after hitting the colored water.)*
- How did the final temperature of the clear water compare with the final temperature of the colored water? *(The colored water's temperature increased more than the temperature of the clear water.)*
- How is the amount of light that was reflected and transmitted related to the amount of heating? *(The less light reflected and transmitted, the warmer the beaker got.)*

Students know that light can be reflected or transmitted, but from this investigation, they should have noticed that some light was neither reflected nor transmitted so it must be doing something else. The beaker with the colored water, which had more missing light, had a greater increase in temperature. The missing light interacted with the water in a new way—it was absorbed and made something happen (it caused the water to heat up).

Introducing Homework 8.2 – Absorption of Light

Homework 8.2 asks students to recall the three ways that light interacts with objects and to apply the relationship between light absorbed and temperature rising to wearing a jacket outside. Use this homework as an assessment of students' understanding of how light interacts with objects and what happens as a result.

Introducing Reading 8.2 – Solar Power Plants

You might prepare students for this reading by asking them what they already know about power plants, or what they think a solar chimney would be used for, or you might use the "Getting Ready" question. Tell students that you will use the last question of this reading to begin the next class period, then use it to check their understanding of transmission as it relates to the in-class activity.

Materials – Activity 8.3

For Each Student

- Activity Sheet 8.3

Activity 8.3 – Keeping Track of Light

Homework Follow Up

Using your homework as a reference, what are the three ways that light interacts with objects and materials? *(First, it can bounce off by scattering or reflection; second, it can be transmitted; and third, it can be absorbed.)* As students name each interaction, record it on the board.

- Which beaker reflected and transmitted the most light? What evidence showed this? *(The clear water reflected and transmitted the most light, as evidenced by measurements taken from the surface and the bottom of the beaker.)*
- Which beaker absorbed the most light? What evidence showed this? *(The colored water absorbed the most light. The same amount of light hit each beaker, but less was reflected and transmitted by the colored water, which means it must have been absorbed.)*

With the beaker investigation, students discovered that when light hits an object, some is scattered or reflected, some is transmitted, and some is absorbed. The total amount of light divided between these three interactions can be shown with the equation:

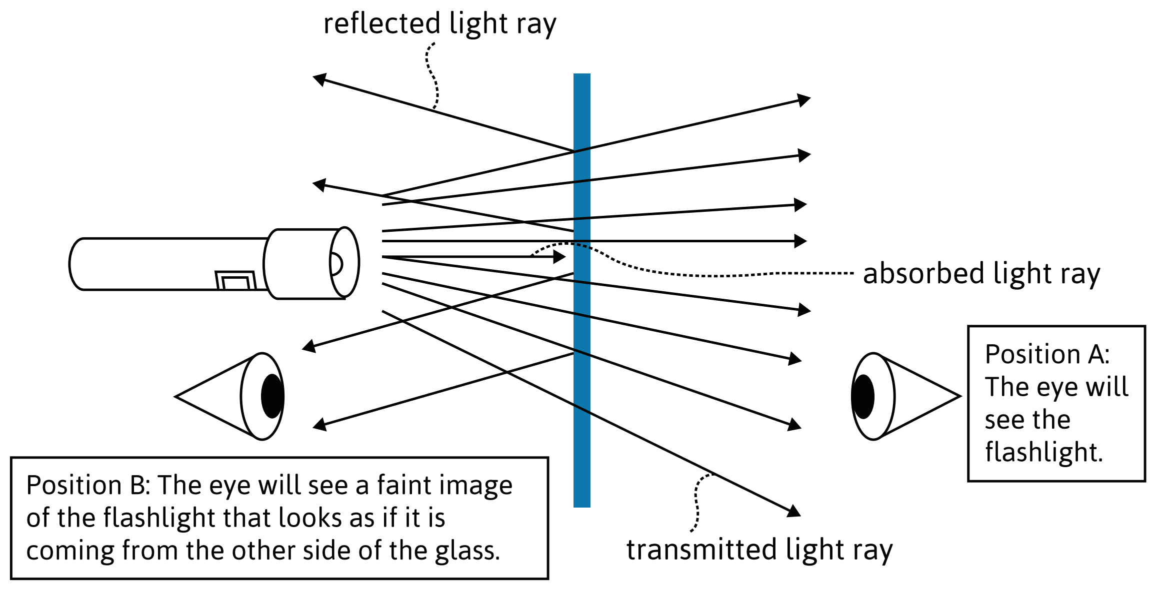
Total light hitting an object	=	Scattered/reflected light	+	Transmitted light	+	Absorbed light

The beaker investigation also provided evidence that not all objects interact with light in the same way. For example, objects that transmit a lot of light, like glass or the beaker of clear water, will neither reflect nor absorb much light.

Use a window or a piece of glass to show students that when a flashlight is shined on glass, most of the light is transmitted, but it is still possible to see a faint image of the flashlight, indicating that some light was reflected.

In this activity, students use the consensus model and revise it to understand what happens when light hits a pane of clear glass. Since you are using a flashlight that only sends light out in one direction, the drawing will look a bit different from what students have seen before, but the key elements of the consensus model are still there: a light source (flashlight), an object (glass pane), and the eye. As before, the model represents the light leaving the light source with arrows.

Draw the following picture on the board, starting with the flashlight and glass. Draw rays leaving the flashlight and going to the glass, but do not complete them yet.



What will happen to the rays after they get to the glass? *(Most will be transmitted, but some will be reflected. Students may not realize that some will also be absorbed.)*

Complete most of the rays so that they go through the glass. Draw a few rays that are reflected and one or two that are absorbed. Finally, draw an eye at Position A. Ask the following questions.

- What will a person at Position A see? *(the flashlight through the glass)*
- What will a person at Position B see? *(a faint image of the flashlight)*

Have students look back at the equation. It shows that a certain number of light rays leave the flashlight, and each light ray must be reflected, transmitted, or absorbed. For glass, the majority of rays are transmitted, a few are reflected, and a very small number are absorbed. The light rays coming out of the flashlight must be equal to the number reflected, plus the number transmitted, plus the number absorbed.

Revisiting Models

If we replaced the eyes at Positions A and B with a light sensor, which position would you predict a higher reading? A lower? Why do you think so? *(Students may predict higher readings at Position A than B, because more light is transmitted than reflected. It is important that students provide a rationale for predictions.)*

Demonstrate each measurement. This is similar to what happened when the beakers of water were heated and the reflected and transmitted light were measured. One of the key features of scientific models is that they can be used to make predictions. This is one example of using a model to predict, in this case, how the readings of a light sensor will change from one side of glass to the other.

On Activity Sheet 8.3 are incomplete diagrams of a flood lamp hitting beakers of water, just as in Activity 8.2. Have students use what they learned from the investigation with the beakers to complete the diagram.

It is important that students' drawings be completed with the following features:

1. More rays transmitted by the clear water than the colored water
2. More rays reflected from the clear water than the colored water
3. Fewer rays absorbed by the clear water than the colored water

Although light rays will be refracted (bent) as they travel through the water, this effect is not included in the previous drawings because refraction is not a learning goal of this unit. Students' drawings should not be expected to illustrate refraction. See the Preparation section for more about refraction.

Add the following to the Scientific Principles list:

- When light reaches an object it is scattered or reflected, transmitted, absorbed, or some combination of these.
- Light can make things happen when it is absorbed.

Materials – Activity 8.4

For the Teacher
- (1–2) light-related phenomena* (from Activity 8.1)

For Each Student
- Activity Sheet 8.4
- Homework 8.4
- Reading 8.4

*This item is not included in the kit.

Activity 8.4 – Revisiting Phenomena Caused by Light

Demonstrate again at least one of the phenomena from the beginning of the lesson in which light was used to make something happen. (See Teacher Background Knowledge for options). Provide students with time to respond to the prompts on Activity Sheet 8.4. Give them time to talk in pairs, and/or direct them to the conservation equation to aid their thinking.

Ask: "Where do reflection, transmission, and absorption play a role in this phenomenon? Based on the demonstrations, should a device that uses light to make something happen have more light reflected, transmitted, or absorbed? Why?" (*Most of the light needs to be absorbed to make something happen. They might give examples such as a solar cooker helping light be absorbed to heat something, a solar calculator absorbing light to generate electricity, or the radiometer absorbing light to make it move.*)

Add the following principle to the Scientific Principles list: Light can make things happen when it is absorbed.

Introducing Homework 8.4 – Absorption of Light

Homework 8.4 asks students to think about how devices use reflected, transmitted, and absorbed light. Students are asked to use data to evaluate how much light was absorbed by a variety of objects.

Wrapping Up the Lesson and Learning Set 2

Based on what we have learned, what questions can be answered now from the second group on the DQB?

Have students think back to their observations of the optical illusions in the first lesson. To help students recall the images, the anchoring activity can be set up again, but it is not essential.

Where do you think scattering or reflection, transmission, and absorption might have been involved? (*Light was scattered by the paper, light was transmitted by the filters, and absorption occurred when light hit the paper and the filters.*)

Direct students' attention to the DQB. They should see the process of constructing an initial model, gathering additional evidence, evaluating the model, and revising it. This is the same process that scientists go through in developing ideas about how the world works. Scientists seek to construct good models that will predict and explain many phenomena. As they do, they keep evaluating their models, looking for their limitations, and deciding whether to revise the models to make them better at meeting their intended purpose.

Encourage students to add relevant questions and answers to the DQB and to their Driving Question Notes. Encourage the progress students have made in the investigations and toward answering the Driving Question: Can I Believe My Eyes? Explain that the patterns they observed in the strange images from the first lesson are related to different colors of objects and light. They have yet to explain why objects can appear as different colors and will focus on that in the next set of investigations.

Introducing Reading 8.4 – Solar Energy

This reading introduces the concept that light carries energy, and this energy is transferred to an object when it absorbs light. The transferred energy is responsible for making things happen like spinning, heating, electricity, or even growth in plants. Ask: "What are some ways that we use solar power or solar energy? Would using solar power for things like cars, televisions, or ovens be a good idea?" Students should come to class ready to talk more about the pros and cons of solar energy.

Lesson 9

What Is the Opposite of White Light?

PREPARATION

Teacher Background Knowledge

Mixing Light

Mixing different colors of light is not the same as mixing the same colors of paint. When colors of light are mixed, nothing new is created. The combination just appears like a new color. This is a psychological phenomenon and has nothing to do with the nature of light but rather with the nature of your eyes and mind.

When paint is illuminated by white light, the paint scatters all the colors of light whose combination results in the color of the paint and absorbs all the remaining colors in the illuminating light (white light is made of many colors of light); thus, red paint scatters red light but absorbs others. When different colors of paints are mixed, each color of paint in the mixture still absorbs the same colors of light as it would if it had not been in a mixture. A mixture of paints absorbs many more colors of light than each color of paint in the mixture would have done independently. The result is that fewer colors of light are scattered by the mixture than by each color of paint independently. Since less light is scattered, the mixture of paints appears to be darker than the original colors. Physicists say that paint mixing leads to color subtraction from the illuminating light.

Students are more familiar with mixing paint than mixing lights—they are almost always surprised to see that mixing green and red light gives yellow.

New colors can be created not only by mixing red, green, and blue, but also by mixing any colors. For example, when purple, blue, green, yellow, orange, red, and others are mixed (think of all the colors in a rainbow), we see white. In principle, you can use many different colors, not just red, green, and blue, to create any color you want. The reason the computer simulation, color film, digital cameras, and most other appliances use red, green, and blue to create new colors is because they simulate the way the eyes work. There are three kinds of cone cells (the cells that are sensitive to color) in the retinas—cells that are more sensitive to red than any other color, cells that are more sensitive to green, and cells that are sensitive mainly to blue. Therefore, with regard to color, technology has tried to copy nature.

Activity 9.1

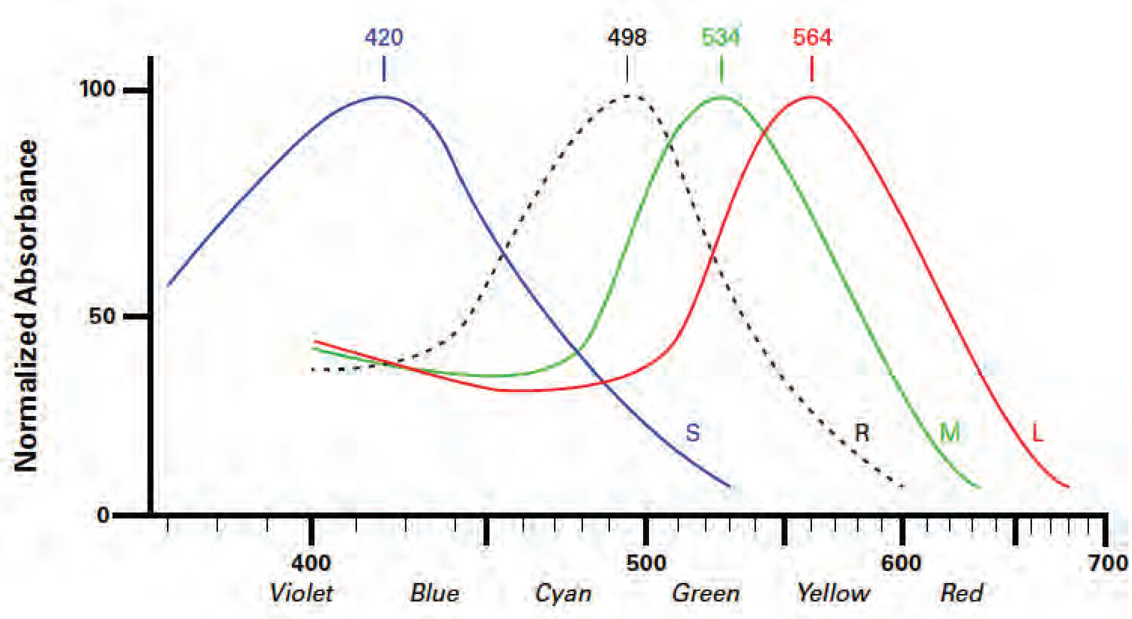
This activity deals with information that is not required by NGSS. However, without it, students will not be able to fully understand the concept of color mixing.

Color mixing activities are often done using old-fashioned overhead projectors or other powerful light sources, with the light from each source projected through a different colored filter. Using a strong light source results in dramatic results, easy for students to observe, question, and begin to make sense of. Because overhead projectors are not likely to be found in schools, and only very powerful flashlights work as a substitute, an "Additive Color Mixing" simulation is available on the Portal for use in this lesson. In addition, an Internet search for "Additive Color Mixing Simulation" (or video) will enable you to find others useful for multiple viewings of this phenomenon. Use video or simulation demonstrations to help students to understand the difference between mixing light and mixing paint/crayon colors with which they are familiar.

Notes in this lesson will refer to "light sources" when providing background information for teachers as applied to various simulations or videos found on the Internet.

Retinal Cells and Wavelengths

The following graph shows the spectral sensitivity of the various types of retinal cells.



Light comes in many different wavelengths, and the eyes perceive the different wavelengths as different colors. When we say that a retinal cell is sensitive mainly to blue light, what we mean is that its peak sensitivity is at 420nm (see the graph), which is a blue wavelength.

Amount of Light

When more light reaches the eyes, we interpret the object we are looking at as being brighter.

If two light sources illuminate a screen, more light from the screen will reach the eyes than if the screen was illuminated by only one light source, so the screen will appear brighter. This is true if the light sources are projecting white light or colored light—more light reaching the screen means more light being scattered to the eyes. So if one light source projects green light and the other red light, the combination of the two must be a color that appears brighter to us than either one separately. In this case, the result is yellow light.

Common Student Ideas

When asked why red light is seen to come from a light source that emits white light, students may suggest that the white light had been changed in some way. Students may say that the white light projects the color of the filter forward. The scientific explanation is that some wavelengths of light are transmitted through the filter, and other wavelengths of light are absorbed by the filter. Those that are transmitted appear red to us. This lesson introduces students to color mixing of the three primary colors: red, green, and blue. Lesson 10 provides evidence that filters and objects selectively transmit, scatter, and absorb different colors of light.

Setup

Driving Question Board

Before class, make sure that the students' questions that are relevant to the third learning set are posted on the DQB. The following questions are examples of questions that might have been suggested that are related to the color of objects or light: Why are some people colorblind? What do colorblind people see? How do they make black light? Why do colors fade in the sun?

Activity 9.1 – Color Mixing

Have the school's computer administrator set the computers in the lab or the classroom to show millions of colors. Use the Additive Color Mixing simulation on the Portal or another that you locate on the Internet using "Additive Color Mixing simulation" (or video) as a search term.

Color Mixing

The computers have to be set for millions of colors, and Shockwave needs to be installed before your students can use this simulation. Contact the computer administrator far enough in advance so that the administrator can make the necessary changes. It is always good to mirror a website, if your school's network has this capability, before sending your student there. This will allow the students to access the site much faster and complete the activity even if the website or your school's access to the Internet is down. Speak with the computer administrator about this possibility.

Safety Guidelines

Refer to IQWST Overview.

Differentiation Opportunities

Refer to IQWST Overview.

LESSON 9

What Is the Opposite of White Light?

TEACHING THE LESSON

Performance Expectations

Students will

- investigate color mixing and its results.
- use the consensus model to describe the path light takes and the interactions it has as it travels from a projector to a screen and from there to their eyes.

Building Coherence

In this lesson, students investigate issues related to color in order to answer questions in the third quadrant of the DQB: How Can Light Have Different Colors? This lesson builds on the conditions for sight and how light interacts with objects and materials. Students revise the consensus model related to color. Lessons 10 and 11 will demonstrate how color can be understood using the concepts that have been learned up to now.

Timeframe

3 Class Periods

Overview

Activity 9.1

- Use a computer simulation to explore how an almost limitless variety of colors, including white, can be created by mixing red, green, and blue light.
- Observe images of the human eye and learn how the retina is constructed to detect color.
- Observe images of a light sensor in a digital camera, explain how it detects color, and draw parallels between the retina and a light sensor.

Homework Follow Up

- Thinking about the first question in your homework, which potato did you predict would be hotter? Why? (*The potato without foil would be hotter, because it would absorb more light, while the foil would reflect it. More absorbed light results in a greater increase in temperature.*)
- Look at the data table in the homework showing scattered, transmitted, and absorbed light. Which type of light is important for seeing the objects? Explain. (*Light must be scattered from the objects back into their eyes to see the objects.*)

Reading Follow Up

Discuss the pros and cons of solar energy, supporting students in understanding that light carries energy, and this energy is transferred to an object when that object absorbs light. This core concept about energy is a basic building block of all future understanding of energy, thus it will be revisited throughout IQWST units.

Introducing the Lesson

Direct students' attention to the DQB and questions that have not yet been answered related to color, which is also an important aspect of the hidden message. The next set of investigations will focus on the question: How Can Light (and objects) be Different Colors?"

Materials – Activity 9.1

For the Teacher

- (3) colored filters—red, green, and blue

If Available:

- (3) overhead projectors* (or digital projectors)

If Not Available:

- additive color mixing simulation, available on the Portal

For Each Student

- Activity Sheet 9.1
- Homework 9.1

*This item is not included in the kit.

Activity 9.1 – Mixing Colors of Light with Projectors

Explain that today's investigation will revisit and connect some ideas from previous investigations as well as demonstrate a new interesting phenomenon that we will be investigating using computers.

Students use Activity Sheet 9.1 to write about why the screen appears brighter when the light is shining on it than when the projector is off. Remind them to think about the consensus model in developing their explanation and that developing explanations is one way to engage in the modeling practice.

Remind students that they do not have evidence to explain how the white light became red at this point. They will examine this phenomenon in an upcoming investigation.

Mixing colors of light is not the same as mixing colors of paint. When colors of light are mixed, the results appear brighter than the original colors. On the other hand, when colors of paint are mixed, not only do you get a different color, but also the resultant color appears darker than the original colors. In order to understand this difference, you will need to investigate the way in which different colors of light are absorbed, transmitted, and scattered by objects.

Materials – Activity 9.2

For Each Group

- (1) computer connected to the Internet*

For Each Student

- Activity Sheet 9.2

*This item is not included in the kit.

Activity 9.2 – Mixing Colors of Light on Computers

Organize students in groups of three or four at the computers. Distribute Activity Sheet 9.2. Students should read the instructions on the website and investigate how to make different colors by combining red, green, and blue light. Make sure each student has at least one opportunity to operate the computer's mouse. While one person is operating the mouse, the others can suggest ways to tune the red, green, and blue light in order to obtain the desired color.

How much red, green, and blue light should be mixed to make the circle white?

Write the suggestions on the board and instruct students to copy the suggestions to their activity sheets. Have students test their predictions by mixing the amounts that were suggested. If it turns out that those amounts do not produce white light, encourage students to experiment until the circle becomes white. When students come up with a white circle, they should record the values on their activity sheets. Have students discuss with their group why this combination made white.

What combination of red, green, and blue led to white? Why? (*While students should agree that red, green, and blue all have to be at their maximum intensity in order to get white, there will likely be little conviction why this must be so.*)

When red, green, and blue lights are seen together at maximum intensity, the brain interprets this as white. There actually is no such thing as the color white. White is always a combination of other colors that is interpreted by the brain as white.

How much red, green, and blue should be mixed to make the circle black?

Write the suggestions on the board and instruct students to copy the suggestions to their activity sheets. Have students test their predictions by mixing the amounts that were suggested. If it turns out that those amounts do not produce black, students should experiment until the circle becomes black, and record the values on their activity sheets. Have students discuss with their group why they think this combination made black.

What combination of red, green, and blue led to black? Why? (*While students should agree that red, green, and blue all have to be at their minimum intensity in order to get black, there will likely be some disagreement why this must be so.*) Remind students that in a previous investigation, they looked into light boxes without letting any light in. Just like the brain interprets all colors at maximum intensity as white, it interprets no light as the color black. There is no such thing really as the color black. Black means there is no color, no light at all.

How much red, green, and blue should be mixed to make the circle light gray? How about dark gray?

Write the suggestions on the board and instruct the students to copy the suggestion to their activity sheets. Have students test their predictions by mixing the amounts that were suggested. If it turns out that those amounts do not produce gray, have students experiment until the circle becomes gray, and record the values on their activity sheets. Then have students try to produce a different shade of gray. Have students discuss with their group why they think these combinations made different shades of gray.

What combination of red, green, and blue led to gray? Why? (*It is important that students agree that red, green, and blue have to be at the same intensity, but somewhere between maximum and minimum in order to obtain gray. The lower the intensity the three colors are set, the darker the shade of gray will be. Therefore, gray is just something between black and white, which should not be new to the students.*)

Computer screens only emit red, green, and blue light, but on the screen you can see also purple, yellow, and brown. How do you think the screen makes these different colors? (*By mixing different amounts of red, green, and blue light at different places on the screen, the computer makes it appear like there are different colors in different places.*)

Materials – Activity 9.3

For the Teacher
- (1) projector*
- PI: Eye Close-Up (from Lesson 4)
- PI: Eye Diagram
- PI: Retina
- PI: Parts of the Retina
- PI: Camera
- PI: Charge Coupled Device

For Each Student
- Activity Sheet 9.3
- Reading 9.3

*This item is not included in the kit.

Activity 9.3 – How Color Sensors Work

Remind students that in Lesson 4 they learned about how the eye senses light, but they did not learn about color vision. Explain that they are going to revisit and expand what they learned about the eye in order to understand how the human eye sees colors. As new information about the eye is learned, students should make notes in the space provided and answer the questions on the activity sheet.

Display PI: Eye Close-Up. Direct students' attention to the pupil in the center of the eye. Based on what we have learned about light, why do you think the pupil looks black with a white spot on it? (*Black is the color we see when there is no light, so the pupil must be black, because no light is being scattered from that area back to the camera or their eyes. There is a white spot because the light from the camera flash reflected off of that area back to the camera. Students may also say that other light from the flash was absorbed by the pupil or reflected away from the camera.*)

Explain that the pupil is like a window into the eye that is covered by very high-quality, flexible, transparent, and smooth material. This covering is called the cornea. Almost all light that reaches the pupil goes through the cornea and enters the eye; only a small fraction of it is reflected.

Replace PI: Eye Close-Up with PI: Eye Diagram. Explain that when a person sees an object, light from the object comes from the left and enters the eye through the cornea and then through the lens, which is another high-quality transparent material. The iris is the name for the colored ring you can see around the pupil. The light continues through the eye (which is filled with a transparent water-based fluid) and reaches the back of the eye, called the retina, where it is almost completely absorbed. You may have seen photos where the people have red eyes. This red-eye effect is the result of red light that has been reflected by the retina, come back out of the eye through the lens, pupil, and cornea, and continued moving to the left until it reaches the camera.

Display PI: Retina. The retina is full of small cells that are sensitive to light. Some are sensitive to different colors of light and are called cones because they are shaped like pinecones. Others shut down at normal light levels and become active only when the light is very weak. When the light is this weak, the cone cells do not work. The cells that work only at very weak light intensities are called rods. They are rod-shaped. When light hits any of these cells, they produce an electric signal that is carried by the optic nerve to the brain.

Display PI: Parts of the Retina. This image shows the cones and rods from the side. There are a lot more rods than cones in this photo. This is not true for all parts of the retina. There are three different kinds of cone cells. One kind is sensitive mainly to red light, a second kind is sensitive mainly to green light, and a third kind is sensitive mainly to blue light. When a person sees red light, the red cones do most of the signaling, which goes to the brain. When a person sees green light, the green cones do most of the signaling, and likewise when blue light is seen.

Both red and green cones are equally sensitive to yellow light. When the brain gets equal signals from both green and red cones, it interprets this as yellow light. That is why red and green light together look like yellow. It is because red light makes red cones signal and green light makes green cones signal, so the brain gets similar signals from them, just as it would if you were seeing truly yellow light. You can use a similar explanation to understand why you see the mixture of any two colors of light as if it was a different color—they make cones signal in combination, which is interpreted by the brain as a new color.

Why do you think the computer simulation used red, green, and blue light rather than other colors of light to make new colors? (*Red, green, and blue correspond to the colors sensed by the cones in our eyes.*) Answer the students' general interest questions about the eye, as long as they are related to color vision (for example, do not go into the lens and its involvement in sight).

Display PI: Camera. Call students' attention to the fact that in both the eye and the camera, light comes from the left, goes through an opening (called the iris in the eye and the shutter in the camera) and continues through until it reaches the back. The back of the eye is called the retina. The back of a camera is called the film (if it is a camera that uses film) or a CCD (if it is a digital camera). The next reading will talk about how color film works. Now they will learn more about how the CCD in a digital camera works.

Display PI: Charge Coupled Device. The image shows a CCD on the left. Its actual size is 30mm across or about 1in. A photographer took the small square in the bottom right-hand corner of the CCD and enlarged it. The white lines in the enlarged image are very thin electrical wires that take electrical signals from the CCD to the miniature computer that is in every digital camera. An artist took the small square from the photo in the center and drew how it looks. In reality, there are no microscopic cups on the CCD—the surface is flat—but the artist felt that the cups would provide a visual to explain that there are small circular areas that are sensitive to light.

The cups are arranged in rows of three—one red cup, one green cup, and one blue cup. This is not the color of the cups but the color of light to which they are sensitive. Just like there are three types of cones in the retina, there are three types of light sensors on the CCD. Therefore, the CCD was made to simulate the way the human eye sees.

Wrapping Up the Lesson

- What new questions do you have about the mixing of different colors of light to make new colors? Have the students complete the questions on Activity Sheet 9.3.
- When we looked at the red and green, the overlapping area looked yellow. Why do the eyes perceive the mixture of red and green light as yellow? (*Red and green cones in the eyes are equally sensitive to yellow light, so when it enters the eye, red and green cones both send signals to the brain, and the brain interprets the signals as yellow.*)

Have students look around the room. Call attention to the incredible amount of detail that can be seen. All this detail is a result of objects absorbing and transmitting some colors of light and scattering the rest. Some of this scattered light enters the eyes through the pupils and reaches the retinas, where it is absorbed by the billions of cells there. These cells make electrical signals according to the color and the intensity of the light that reaches them and transmit the signals, by way of the optic nerve, to the brain where an image of what is outside is created.

Add the following principles to the Scientific Principles list:

- When different colored lights are mixed, they appear as a new color, brighter than the original colors.
- White light is a mixture of all colors of light—it is the brightest color. Black is the color associated with the absence of light.

In the next lesson, students will do the opposite of what they did today—rather than combining red, green, and blue light to make new colors of light, they will be taking apart different colors of light to discover from which colors they are made. They will realize that by using proper instruments, they can do something their eyes and brains cannot do—tell which colors of light make up the colors they see.

Introducing Reading 9.3 – Making Color Photographs

This reading should be given only after Activity 9.3 has been completed. It starts with what was learned about digital cameras in Activity 9.3 and continues to explain how color film can sense and record different colors.

Ask: "Have you ever seen a black-and-white movie? Why do you think older movies were made in black and white?" (It is important to link this reading to what students are doing in class—to have them think about light, colors, filtering, transmitting, absorbing, and scattering or reflecting as they read. What they learn in class can help them make sense of this reading, but the concepts are difficult. Guide the reading by posing a question or two that you want students to be able to talk about in the next class period, helping them focus on an important aspect of the reading.)

Lesson 10

How Do Objects Change the Color of Light?

PREPARATION

Teacher Background Knowledge

Color and the Speed of Light

- The speed of light changes when it passes from one medium to another. This change in speed can cause light to change direction. This phenomenon is known as refraction.
- When traveling through a medium, the speed of light is slightly different for the various colors of light. Only in a vacuum is it the same for all of them. When multicolored (polychromatic) light goes from one medium to another, the different colors change speed differently. This makes each color change direction differently. Since each color moves now in a different direction, they start moving away from each other. This phenomenon is called color dispersion.
- A prism compounds the effect of color dispersion. Light passing through a prism goes through a medium change twice: once when entering the prism and once when leaving it. The faces of the prism are built at an angle to each other so that the refraction of the light at each surface happens in the same direction rather than in opposite directions, thus reinforcing each other.
- Students may know the mnemonic ROY G BIV, which stands for the colors of light in the visible spectrum. A question students often ask is "What is indigo?" Some sources say when Isaac Newton discovered the visible spectrum, he thought there should be seven colors because there were seven notes in the musical octave, so he included the color indigo as the seventh color.

C-Spectra/Diffraction Grating

- C-Spectra is a transparency that has a picture of a diffraction grating printed on it. Although there seems to be nothing printed on the transparency, there are actually thousands (if not millions) of microscopic lines on it. These lines are too thin to be seen by the naked eye.
- A diffraction grating is a series of equally spaced microscopic lines and transparent spaces. The distance between the lines is about a micrometer, the same size as a typical wavelength of visible light (about 0.3–0.7 micrometers).
- When monochromatic (single-colored) light passes through a diffraction grating, it creates a pattern that looks like a series of bright areas separated by dark areas. Try this before the lesson. Illuminate a wall with a red laser pointer. Now put a piece of C-Spectra between the laser and the wall. You will see a series of bright red spots on the wall.
- Diffraction is a complex phenomenon that is based on the wavelike nature

of light. It is not recommended to get into this with your class, as it will probably only confuse them and is not needed to understand the results of using C-Spectra, just like you do not have to understand how a microscope works to be able to use it to see small objects. If a student pushes you on this topic, you can provide them with the optional reading that appears at the end of this lesson.

- If a different monochromatic light, for instance green, is passed through C-Spectra, it too will create a series of bright spots. There will be two differences between the spots created by the red light and by the green light: (1) the red light will make red spots and the green light will make green spots, and (2) the distance between the spots will be different. This means that if you mix red and green light and shine them together through C-Spectra, even though the mixed light looks yellow, you will get red and green dots at different places on the wall. Therefore, even though your eyes cannot determine the color composition of the mixed light, C-Spectra can help you do this analysis.
- White light is made of many colors of light. In fact, it is often made of all the colors of light. When you pass white light through C-Spectra, each color makes a bright spot at a different point. Since the difference between many of these colors of light is very small, the distance between their bright spots is very small too, so it seems to you as if the color changes continuously from violet to blue to green to yellow to orange to red—all the colors of the rainbow.

There are many more colors coming from the C-Spectra than those mentioned. The colors change gradually from one to another, so there are many shades of blue, green, and so on. However, for the sake of this lesson, assume that there are a finite number of colors.

Earth, Moon, and Sun

The outer shadow where Earth blocks part but not all of the sun's light from reaching the moon is called the penumbra. The inner shadow where Earth blocks all direct sunlight from reaching the moon is called the umbra. A penumbral eclipse occurs when the moon passes through Earth's penumbra. This eclipse is hard to notice with a bare eye. A partial lunar eclipse occurs when only a portion of the moon enters the umbra and it is clearly seen. When the moon is entirely within Earth's umbra, a total lunar eclipse occurs.

The moon's speed through the shadowed areas is about one kilometer per second (2,300mph), and the total time between the moon starting to enter the shadow and the moon entirely leaving the shadow can last up to 3.8 hours. A total eclipse may last up to 107 minutes.

Common Student Ideas

When asked how people see the color of an object, students often respond that color is a property of the object. The scientific explanation is that the pigments in objects selectively absorb and reflect the colors in light. For example, a book is red because it absorbs green and blue light while reflecting red light.

Setup

Specific instructions for activity setup are embedded within the lesson.

Safety Guidelines

Refer to IQWST Overview.

Differentiation Opportunities

1. You might choose to demonstrate how a prism works or show students a photo of white light separated into colors by a prism. To demonstrate how a prism works, place a prism in the path of the light from a projector to the screen and slowly turn it around until colors appear on the screen. Tell students that the prism is separating the colors that were mixed together in the white light. How it does this is not important for the class to learn in this unit, but the demonstration can help students to see in another way that white light is a mix of colors. You might, instead, assign particular students to investigate prisms and provide one for them to demonstrate and explain to the class.

2. Reading 10.3 is an optional reading on diffraction designed to enable advanced students to go beyond the lesson. They might couple this with Internet research and a poster or other representation designed to represent their understanding and perhaps to share with classmates.

Lesson 10

How Do Objects Change the Color of Light?

TEACHING THE LESSON

Performance Expectations

Students will

- carry out an investigation to examine colors of light scattered and absorbed by different colored pigments.
- revise the model of light and use it to explain phenomena involving how people see color.

Building Coherence

In Lesson 9, students investigated what happens when different colors of light are mixed. In this lesson, they learn how to separate colors of light. This enables students to gather evidence for answering questions in the third quadrant of the DQB and for explaining how people see colored objects when light shines on them.

Timeframe

3 Class Periods

Overview

Activity 10.1

Use C-Spectra to learn how an object's color is related to the colors of light it scatters.

Activity 10.2

Revise the consensus model so it can be used to explain color-related phenomena.

Reading Follow Up

Take time to talk about Reading 9.3.

- Why does there need to be three layers in color film? (*Any color is a combination of red, green, and blue light. Each layer is sensitive to a different color of light.*)
- Why do the layers in the film need to be transparent to all colors other than the one it absorbs? (*Light that is sensed by lower layers needs to be able to be transmitted through the upper layers, so that it can reach the layer that is sensitive to it.*)

Materials – Introduction

For the Teacher

- (1) projector*
- PI: Red Rectangle
- (1) red object* (such as an apple)

*This item is not included in the kit.

Display PI: Red Rectangle with the projector. Hold a red object (an apple is an easy option) so that all students can see it.

- Why do you see the square on the screen as red? (*Red light is scattering off the screen and being sensed by the red-sensing cones in our eyes.*)
- Why do we see this object as red? (*Answers will vary; it is only important that students start to think about the situation and articulate their ideas.*)

Explain to students that they have gathered data that provides evidence to help them understand how light can be mixed to make new colors, but they are not yet able to explain why a person sees different objects as different colors under the same light. In next investigation, they will gather data to help explain this phenomenon.

Direct students' attention to the consensus model. The model has been revised to include how light interacts with objects by scattering, transmission, and absorption. However, the model still does not help us understand color. We will need to revise it to account for new evidence.

Materials – Activity 10.1

For the Teacher

- (1) projector*
- PI: White Rectangle
- PI: White Square
- (1) sheet of C-Spectra
- sheets of black paper with colored lines printed on them

For Each Group

- (1) square of C-Spectra

For Each Student

- Activity Sheet 10.1
- Reading 10.1

*This item is not included in the kit.

Activity 10.1 – Analyzing Color Composition

What situations have you seen light separated into different colors? (*Students might mention rainbows in the sky, bubbles, an oil film on pavement, or prisms.*)

Display PI: White Rectangle. Based on the computer simulation in Lesson 9, why does the light making the white line on the screen look white? (*The maximum amounts of red, blue, and green light are mixed together.*) Have the students write an explanation of why they see a white line on Activity Sheet 10.1.

✓ There should be a consensus that white is a mixture of other colors of light, although it may require a bit of directional probing to get this consensus. If some students do not agree with this explanation, they may need to review the former lesson.

Put a piece of C-Spectra over the lens of the projector pointing at the screen. Do not let the C-Spectra touch the projector as it may melt. You should see on the screen two colorful images to the sides of a white slit at the center. If the images lie above and beneath the white rectangle, rotate the piece of C-Spectra by 90°.

What colors do you see on the screen?

Make a list of the colors students mention on the board. The list should include at least the following colors: red, orange, yellow, green, blue, and violet (or purple). If other colors are mentioned, you can add them to the list. As students will be using this list later, have them copy it to their activity sheets. Explain to the students that C-Spectra takes the light going through it and separates it into its constituent colors.

Tape one of the black sheets with a colored line to the board so that the colored line is vertical. Project PI: White Square and locate the black sheet on the board so that the projector illuminates the colored line and the black sheet but not the white board behind the black sheet. Give each group a square of C-Spectra. There is no need to dim the classroom lights.

What color is the light that is illuminating the sheet of paper on the board? (*Students will likely respond that it is white. Students may respond that it is a mix of many different colors that appears as white.*)

Have students look through the piece of C-Spectra at the colored line on the black sheet. Have students list on Activity Sheet 10.1 the colors of light they identify when looking at the colored stripe. Replace the black sheet with another one with a different colored line. Again, ask the students which colors of light they see using the C-Spectra.

- If the stripes were illuminated with white light, why do they scatter only some colors of light and not all of them? Have students write their ideas on their activity sheets and then discuss their ideas with other group members.
- Now that you have had a chance to talk about the question in your groups, what did your group think about why only some colors of light were scattered by the different stripes? (*The stripes absorbed certain colors and scattered others depending on the color of the stripe.*)
- If you had illuminated the stripes with red light, rather than white light, would you have been able to see all the stripes? Explain. (*When illuminating with red light, they would have been able to see only those stripes that scatter red light. The green and*

blue stripes should appear black, because these stripes do not scatter any red light, and therefore, they should blend in with the black background and not be visible.)

- Based on what you saw with the C-Spectra, which stripes are able to scatter red light?
- If the green and blue stripes do not scatter red light but absorb it, what would they look like if they were illuminated by red light?
- What colors would you be able to see if you illuminated the stripes with green light? (*When illuminating with green light, they would be able to see those stripes that scatter green light. The red stripe should appear black, because it does not scatter any green light, and therefore, the red stripe should blend in with the black background and not be visible.*)
- Based on what you saw with the C-Spectra, which stripes are able to scatter green light?

Summarize that, while the color an object appears depends on the color of light illuminating it, an object is said to be a particular color if that is the color it appears when illuminated by white light.

☑ Ask students to apply what they have learned to answer the question, what colors of light are absorbed by plant leaves? Students should explain that red and blue light is absorbed by the plant leaves. Plant leaves look green because they scatter green light. Since plant leaves do not look white, some colors of light must have been absorbed by them. This question is revisited in the homework.

Add the following to the Scientific Principles list: Colored objects scatter only certain colors of light and absorb the rest.

Introducing Reading 10.1 – Rainbows

This reading focuses on rainbows and why they happen. It also suggests a way to make a rainbow at home. Have students come to class ready to talk about what they have learned. Ask students the following:

- Thinking about what you observed today and have learned so far, how do you think rainbows happen?
- What role do you think light plays in rainbows?
- Why do you think we see rainbows only occasionally?

Reading Follow Up

If possible, have a place where students who arrive early can do the activity if they were unable to do it at home. Ask: "How is the water in raindrops, a prism, and the C-Spectra similar and different?" For discussion purposes or as an assessment, you might have students choose one of the three, and explain how it works based on what they learned from the reading.

Materials – Activity 10.2

For the Teacher
- (1) projector*
- PI: Light Hitting a Transparent Object
- PI: Polychromatic Light
- PI: Light Scattered by Red Filter
- PI: Light Absorbed by Red Filter
- PI: Light Reflecting Off an Apple

For Each Student
- Reading 10.2

*This item is not included in the kit.

Activity 10.2 – Revisiting the Consensus Model

Students need to evaluate the consensus model based on the new data on light and color using relevant features that have been discussed throughout the unit. Have them look at the consensus model. Ask: "How useful is the consensus model for explaining the color-related phenomena that we investigated using the colored stripes?" *(It does not account for different colors of light or different colored objects.)*

- Does the model account for the data you gathered that different colored stripes interact differently with light?
- How does this model explain why people see objects as different colors?
- Have you included the color of light and the color of the object in our consensus model?

Scientists continually evaluate models to see if they account for new data or phenomena and revise as needed.

Show the model developed in Lesson 8 (PI: Light Hitting a Transparent Object), which shows what happens to light when it reaches a transparent object, like a pane of glass. Explain that nothing is perfectly transparent, so most of the light is transmitted, a bit is reflected, and even less is absorbed.

Display PI: Polychromatic Light. It shows white light (multicolored) light reaching a red filter.

- What should be added to this drawing to show what happens to the light after it hits the filter? *(You should show red light being transmitted through the filter and the other colors of light being absorbed. Students may also say that some of the red light should be reflected.)*
- The person holding the flashlight would also see the red filter. What is light doing to help the person see the filter as red? *(Some red light is scattered and reflected back to the eye.)*

Display PI: Light Scattered by Red Filter. Explain that it is not usually necessary to draw all the colors every time they are talking only about white light. For white light, they will continue to use the black or gray lines that they have been using. Students should keep in mind that models show the key ideas that are needed to explain or make predictions about something.

Display PI: Light Absorbed by Red Filter, which is the same as PI: Polychromatic Light and PI: Light Scattered by Red Filter combined, except it uses black lines and arrows for the white light. Explain that PI: Light Absorbed by Red Filter shows a way of representing the same situation using black lines to show white light. Notice that this is easier to draw than using lots of multicolored lines, but it has a drawback. It only shows what happens to the colors that get transmitted or reflected, not those that get absorbed. Since students know that what is not transmitted or reflected has to be absorbed, and they know that black lines are white light, which means every color of light, they can conclude that since all colors other than red are not transmitted or reflected, they must have been absorbed.

The models you have been looking at work to explain how filters produce colored light. What ideas would you need to represent in a model showing how light is transmitted, reflected, and absorbed by a colored, nontransparent (opaque) object like a red apple? *(White light would hit the apple, and all colors but red would be absorbed. Red light would be reflected or scattered. Students may also say that some of the red light could enter the eye of an observer.)*

Display PI: Light Reflecting Off an Apple, which again uses black lines to depict white light. Ask: "How does this drawing show the ideas that were just talked about?" Explain that now that students have revised the model to account for different colors of light and how people see objects as different colors, they can use the model to develop a full explanation of how we see objects, including optical illusions.

Wrapping Up the Lesson

In recent investigations, students have expanded their understanding of light and how it helps people see by investigating phenomena involving color. Based on the data they gathered, they revised their model to allow it to be used to understand phenomena involving color. They have learned all the major ideas needed to understand a wide variety of sight-related phenomena. If students look around, they should be able to explain how people see and why things look the way they do.

Let students know that there is not time to gather data on lenses—items like glasses, contact lenses, microscopes, and telescopes—and how they affect how people see. If this is a particular interest to some students, suggest the Internet as an excellent resource. Science classes in high school, such as physics, often study these phenomena.

Introducing Reading 10.2 – Lunar and Solar Eclipses

This is the fourth in the series of readings on astronomical phenomena (in this case, on what causes lunar eclipses). This reading may be read any time after Reading 6.4 in order for students to make sense of it.

Choose three volunteers. Darken the room and set up the sun, earth, and moon system as in Reading 6.4. Ask: "Where is the moon located in the full moon phase?" *(The moon is directly behind Earth so that there is a straight line connecting the sun with the earth and with the moon.)*

Have the moon stand behind the Earth so that it blocks the light from the sun.

- In this situation, you should be able to see all of the side of the moon facing the sun. It seems that in this situation, Earth should block the sun's light so that nothing reaches the moon—that is, the moon should be in Earth's shadow, and it should be completely dark. However, we learned in Reading 6.4 (about the moon's phases) that this does not happen. Why?

- Have you heard of an eclipse? What do you know about eclipses?

Reading 10.2 will explain that and also why sometimes Earth actually does block the sun's light from reaching the moon. This is called an eclipse.

Introducing Reading 10.3 – Diffraction

This is an optional reading, see Differentiation Opportunities.

LESSON 11

Back to the Anchoring Activity

PREPARATION

Teacher Background Knowledge

Explaining How We See the Optical Illusions

The complete explanation should be similar to the following sequence:

1. Colored light spreads out from the projector (the light source) in straight lines.
2. Most of this light reaches the screen, where it is scattered in all directions. Very little light is absorbed, because the screen is white. The light is scattered rather than reflected, because the screen is rough.
3. The scattered light spreads out in straight lines in all directions. Some of it reaches our eyes and some reaches other objects in the room.
4. The light that reaches objects in the room can be absorbed, reflected, or scattered again.
5. The light that enters our eyes through their pupils is absorbed by the retina, from where a signal is sent to our brains. Our brains interpret the signal as an image of turning circles or of a bulging checkerboard with a green cylinder on it.

Setup

Make sure that the artifacts related to the main concepts of Learning Sets 1–3 are posted near the Driving Question Board. These artifacts include the conditions needed to see, the photos of models the students created, the consensus model with revisions, and the Scientific Principles chart.

Card Game Preparation

If you have time to prepare in advance, copy the questions, answers, and evidence activities from PI: Investigation Map Questions to cards. Prepare 30 cards for each group: 10 with questions, 10 with answers, and 10 with evidence activities. On the back of each card, write Q for a question, A for answer, and E for evidence. If you prefer, you may choose other questions from the DQB and write the appropriate answers. This alternative is less competitive, but it enables more students to participate, unlike a Jeopardy game where there are usually a few dominant students in each group.

Card Game

Each group will receive 10 questions, 10 answers, and 10 evidence activities they did in Learning Sets 1–3. First, they should put the cards in three piles (Questions, Answers, and Evidence). Distribute the Answer cards and Evidence cards between the group members, and leave the Question cards on the table facedown. Each student in his/her turn takes a Question card and reads it to his/her group members. The first student who thinks he or she knows the answer says it, and the group should decide if they accept this answer or not. Students may look at the cards. Then do the same with the Evidence cards. Students should try to find the specific activity they did in class that provided the evidence for this explanation. After matching all the cards, they can try to sequence each Question, Answer, Evidence triplet according to the order in which they were investigated in class.

When all the groups are ready, continue to a class discussion. Let each group share with the class one or two of their Question, Answer, Evidence triplets. During the discussion you can add other questions from the DQB that can be answered based on the evidence from the activities done in class.

Activity 11.2 – Presentations

The main idea is to provide an opportunity for students to present in their own way all the details of how they see an object. Therefore it is important to assign all the steps to groups. It is not important to use all the presentation modes. If all the students choose only one or two models of presentation, that is fine. Divide them into several groups and give each group different places through which light passes to consider, so they will build on each other's presentations to complete the whole explanation. It is recommended to give each group more than one step, because it is difficult to present single steps, so there might be some overlapping in steps between groups. The time they work on preparing the presentations may be limited, so students should not focus on artistic issues, but emphasize the details and accuracy of their explanation. Groups may need materials and resources. For example, a group preparing a physical model may use books or illustrations of the eye and the brain.

⚠ Safety Guidelines

Refer to IQWST Overview.

Differentiation Opportunities

Refer to IQWST Overview.

Lesson 11

Back to the Anchoring Activity

TEACHING THE LESSON

Performance Expectation

Students will use the consensus model and evidence from the unit's activity to explain how people see objects, including optical illusions.

Overview

Activity 11.1
Revisit Learning Sets 1–3, reexamining the DQB questions and the evidence that enables students to answer them.

Activity 11.2
Construct a full explanation of how we see the images with groups of students each using a different form of communication to present.

Building Coherence

Review the main concepts learned so far as they connect to the anchoring activity and provide a full explanation of how we see objects.

Timeframe

2–3 Class Periods

Materials – Activity 11.1	
For the Teacher	***For Each Student***
• PI: Investigation Map Questions	• Activity Sheet 11.1

Activity 11.1 – Revisiting Learning Sets 1–3

The goal of this activity is to summarize and connect what they have learned in all the investigations of light and how people see. Direct students' attention to the DQB. Talk about how the organization of the questions on the board guided the investigations throughout the unit.

Students will work in groups to review the science ideas they have learned in this unit. Groups will gain points with each answer given using evidence from the investigations. Each group will select a representative to answer each question. Each group will have a turn to answer the questions, and the other groups will have an opportunity to respond to incomplete answers.

Choose the kind of game in which your class will engage, and decide how points will be awarded. Display PI: Investigation Map Questions and only the first question. Cover the columns of the answer and evidence activity.

If your students are not ready yet for this review game, give them some time to review their materials in class or at home before the activity. Another possibility is to do only the answers column as a game, and discuss the activities column or part of it with the whole class.

- What are the main science ideas we have learned so far? (*Light travels in straight lines; light can be blocked by opaque objects and cause a shadow, scattering, reflection, transmission, absorption, mixing and separating colors of light, and interaction of different colors of light with objects.*)
- How are these ideas connected to our Driving Question: Can I Believe My Eyes? (*Our eyes are a limited sensor, good for some situations and poorer in others. Learning about the properties of light helps us understand when our eyes may mislead us, or what the limits of our eyes are. For example, shadows are actually areas of no light, reflections are the result of properties of objects and materials interacting with light, and colors are not always what they seem to be because of absorption of light.)*

Materials – Activity 11.2

For the Teacher

(Refer to the setup done for Activity 1.1)

- (1) projector connected to a computer*
- PI: Moving Circles
- PI: Checkerboard
- PI: Applying the Light Model 1

For Each Group

Materials for Physical Model Group(s)

- modeling clay
- marbles
- string
- colored cellophane paper
- shoebox*

Materials for Written Explanations Group(s)

- paper and markers or pens* (explanations will be projected)

Materials for Other Group(s)

- posters*
- colored markers*

For Each Student

- Activity Sheet 11.2
- Reading 11.2
- Activity Sheet 11.3

*This item is not included in the kit.

Activity 11.2 – Explaining How We See Objects, Including Optical Illusions

With the evidence collected throughout the unit, students should be able to give a full explanation of how they saw the optical illusions from the start of the unit and a new optical illusion they will see now. The goal of this activity is for students to explain to someone who has not done the investigations they have done. To do this, they will create a model and use it to communicate an explanation of a phenomenon to someone else.

Display PI: Checkerboard. Ask: "Are the lines near the center of the checkerboard straight or curved? Do you see a bulge near the center of the checkerboard?" Display PI: Applying the Light Model 1. Go back and forth between the two. This is a complex situation, and they should start crafting an explanation of how they see the illusion by tracking the path of the light rays from the light source to our eyes by naming the places in the room that the light rays pass.

What are the places that the light rays pass through or interact with? As students suggest places, write them on the board. Do not ask for explanations yet. The different places include the following:

a. light source (projector)
b. room space (air)
c. screen
d. objects in the room (walls, people, and other objects)
e. retina of our eyes
f. brain (Light does not really get to the brain, but it is part of the explanation.)

The explanation of how they see the optical illusion can be presented in different ways, and people may prefer to have an explanation communicated in a way that is easiest for them to understand. Have students think about the physical models they built as they first started working on the light model. Explain that this time, they are going to use a variety of ways to present the parts of the explanation for how they see the optical illusion and then combine the individual explanations into one collective explanation by the class.

Activity Sheet 11.2 describes six different models that can be used to explain the anchoring activity:

1. Written explanation
2. Musical presentation
3. Consensus model (diagram)
4. Physical model
5. Dramatic performance
6. Artistic drawing

Assign students to groups according to their preferred mode of presentation. There can be several groups of the same mode. Assign the different parts of the explanation (light source to screen, screen, screen to our eyes, our eye, and eyes to brain) to the groups. You may need to assign more than one part of the explanation of the model to some groups. Each group will construct a different presentation of their part of the explanation to how we see the optical illusion. Give students a time limit to finish their presentations. Determine whether students will work during one class, complete the presentation at home, and present at the next lesson. Remind students that while creativity and art in creating their explanations is important to the quality, the most important thing is that they provide a complete explanation that accounts for all the evidence.

After all the groups finish their models, they should present in the order in which light proceeds from one place to the next. Challenge students as they watch each presentation to keep in mind that the goal is to provide a complete explanation of how they see the optical illusion. Have students ask questions if there is some part of an explanation that is not clear to them. Identifying parts that could be made clearer will help improve the whole explanation.

Suggested Prompts

- What led you to choose the model of presentation that you did?
- What are the advantages and limitations of the model that you chose compared to other options?
- What would be the best way to present the complete explanation of how you see the optical illusion?

(*Answers will vary; it is important that students give rationale in terms of the criteria for models.*)

The consensus model is an advantageous model for several reasons: (1) it builds on what they have already done, (2) they have agreement about what its symbols mean, and (3) it uses simple icons.

- What are the different parts of our model that are important for explaining how we see the optical illusion? How can we show them in a diagram using the conventions developed? As students describe each step taken by the light, draw it on the whiteboard.
- What is the difference between scattered and reflected light rays? *(Scattered light rays go in all directions. Reflected light rays are scattered in the same angle they hit the object.)*
- Why does the screen get a bit warm? *(It gets a bit warm because it absorbs some light from the projector.)*
- What would the people in Positions A and B see if a blue filter were held over the lens of the projector? *(With a blue filter, the people would see the white squares as blue and the brown squares as almost black.)*

Wrapping Up the Lesson

Conclude the lesson by explaining that the investigations during this unit have helped to develop a number of ideas related to how light helps people see. Direct students' attention again to the Driving Question: Can I Believe My Eyes? To fully answer this question, we need to investigate how the brain makes sense of the signals sent to it by the eyes. This lies beyond the scope of this unit, so students that are interested in understanding this will just have to continue learning more science!

Mention that one of the assumptions sometimes made is that our eyes are light sensors that can see all the light that is around us. Ask students if there is light that cannot be seen. How would they find out?

Unanswered questions like these are a constant feature of science. Sometimes it is because no one has had a chance to investigate them. Other times it is because we do not yet have the ability to investigate. Science is a process of knowledge construction as new answers and new questions continue to be generated. A sense of unknown and mystery is a part of what makes science interesting.

Materials – Introducing Reading 11.2

- (1) basketball or volleyball*
- (1) marble per student

*This item is not included in the kit.

Introducing Reading 11.2 – Solar Eclipses

This is the final reading in the series on astronomical phenomena. It deals with solar eclipses. Follow up this reading by reconnecting it with the activities done in class to reinforce student understanding. This must be read after Reading 10.4 in order for students to make sense of it. Place a basketball on a desk at the front of the class. Have every student hold a marble in one hand. The students should shut one eye and hold the marble at arm's length, so that it obstructs the line of view between their open eye and the basketball. The students should move the marble closer to or away from their eye just so that it obstructs the basketball, but not more.

With the marble at this distance, have the students move the marble slowly to the right and left so that different parts of the basketball are obstructed. Tell students that they should imagine that their head is Earth, the marble the moon, and the basketball the sun. When the moon blocks part or all of the sun, we say we have a solar eclipse. Tell students that witnessing a total solar eclipse is a very special experience because it becomes completely dark in the middle of the day. Most students may never have a chance to witness one. Reading 11.2 is about solar eclipses.

- While students are holding the marble so that it completely blocks the sun (basketball), without moving the marble, have them open their closed eye and shut the other eye. The sun will no longer be eclipsed. Ask them to explain why. This means that a solar eclipse may be visible from one point on Earth (the place where one of their eyes is located) but not visible at another location (the place where their other eye is located). (*The marble does not block the line of sight between the basketball and the other eye.*)
- Where will the marble be located during a lunar eclipse? Why is a lunar eclipse visible from all locations on the night side of Earth, unlike the solar eclipse, which is visible only at certain locations? (*The moon [marble] will be located behind Earth [head] rather than between Earth [head] and the sun [basketball]. During a lunar eclipse, Earth blocks the sunlight from reaching all places on the moon, unlike a solar eclipse during which the moon blocks the sunlight from reaching some places on Earth.*)

Lesson 12

Infrared Light and the Wave Model

PREPARATION

Teacher Background Knowledge

Visible Light Wavelengths

The specific range of visible light wavelengths (about 400nm–700nm) is not important here, particularly because students are not likely to have had an introduction to the metric prefix, nano. Furthermore, it is neither necessary nor desirable to discuss the full electromagnetic spectrum during this activity. The goal is for students to realize why there is some light that they cannot see, so it is not necessary for them to distinguish between various categories of wavelengths that cannot be seen. You can make a connection to Lesson 10.3, where the cones and rods in the eye's retina were discussed; these retinal cells are not sensitive to the wavelengths outside the visible range.

Hearing Pitches

Children can often hear pitches in the range from 20Hz to 20,000Hz, though each person's range may be slightly different. As people age, the range of pitches they can hear becomes more limited. In this example, the range that students will be able to hear will depend on the volume and quality of the computer's speakers and the distance between the students and the speakers.

Setup

This lesson suggests websites that are ideal for this lesson. If the specific sites are not available, use appropriate search terms to find other applicable resources on the Internet.

Safety Guidelines

Refer to IQWST Overview.

Differentiation Opportunities

1. Students may suggest other investigations that they would like to do based on the activities they have seen in the lesson. Examples might include the following: trying to heat water with the remote; lighting paper on fire using a magnifying glass and remote; trying to make a radiometer move using the remote; or using the light

detector to detect the light. One important factor that you could ask students to consider as they suggest these is whether the remote is equivalent to the type of light that was used to make the above things occur. Based on what students see through the digital camera, the remote might be compared to a small penlight or weak flash-light. Since its intensity is quite weak, you should not expect it to be able to do the same things that a more powerful light source can do. If you choose, you may attempt these additional experiments, but the results may not entirely support the idea that the remote control is emitting light. Rich discussion may result about designing fair tests once students recognize the limitation of using the remote as the light source.

2. You might use the design of an investigation related to this—or to any other activity in the unit—as a final project for the unit, or Internet exploration of other ways in which light waves are used/useful in everyday life, or investigation of questions as yet unanswered on the Driving Question Board. Any of these are possible culminating projects, as is any project that engages students and invites them to *apply* what they have learned to a new context or *extend* what they have learned by going beyond what was done in class, perhaps to *represent* what they have learned in a creative manner (e.g., making a movie, comic book rendition, or children's book to explain a concept).

Lesson 12

Infrared Light and the Wave Model

TEACHING THE LESSON

Performance Expectations

Students will

- develop and use a wave model to explain what distinguishes between colors of light.
- develop and use a wave model to explain what distinguishes between visible and nonvisible light.
- use technologies to explore near-visible bands of light and to relate their wavelength to light that is visible.
- design an investigation to determine whether infrared light is or is not light.
- construct an argument about the role of a light's wavelength in determining its visibility.

Building Coherence

Learning Sets 1–3 developed a model of light that helped students explain how they see things and how light interacts with objects and materials. Up to this point, all light considered was visible. Students now examine infrared (IR) light, which cannot be seen, and a wave model of light that can help them explain why IR is called light.

Timeframe

2 Class Periods

Overview

Activity 12.1

Design and carry out a series of investigations to determine whether a remote control emits light.

Activity 12.2

Use the wave model of light (that scientists use to explain different colors of light and the existence of nonvisible light) to explain why students cannot see light leaving the remote.

Materials – Activity 12.1

For Class

- (1) television or projector*
- (1) remote control that uses IR* (most remotes)
- as many cell phones with cameras* (students can use their own) or digital cameras as can be gathered—if only one is available, an alternative is embedded in the lesson
- (1) poster board*
- (1) small mirror
- (1) blank transparency sheet

For Each Student

- Activity Sheet 12.1

*This item is not included in the kit.

Activity 12.1 – What Is Leaving a Remote Control?

Incorporate ideas such as the following: As you make observations in our next activity, be sure to think about the investigations that have provided evidence for our big ideas about light and how those ideas apply to this new situation. Refer to the Driving Question Board if you need reminders of our investigations.

Standing back from the television, use the remote control to turn the television on and off, or make its volume change. If you are using a projector, use the remote control to change the image shown by the projector. You are just establishing that the remote control works and it can cause a change in the TV. One of the tests for light in Lesson 8 is that light makes things happen, in this case making the TV turn on and off.

Place the TV in the back of the room behind the students and stand at the front of the class facing the students. If you are using a mobile projector, place it at the back of the room and stand at the front of the class facing the students. If you are using a projector permanently mounted to the ceiling, just stand at the front of the class facing the students. Arrange the students in groups, each with a camera-phone or digital camera.

Incorporate ideas such as the following: In your groups, choose a couple of members to look directly at you and the remote control. Choose a couple of other members to look at you through the LCD screen on the camera.

Turn on the TV so that sound can be heard. Hold down the volume button on the remote so that the sound gets louder. If using a projector, hold down a button so that something on the projector changes, such as the brightness or the contrast of the image it projects.

- First, ask group members who were looking directly at you what they observed. *(It is important that students say that they heard the TV get louder [or saw the image on the screen projected by the projector get brighter/darker] but did not see anything coming from the remote.)*

- Next, ask group members who were looking through the LCD screens what they observed. *(It is important that students say that they saw a flashing light coming from the remote control.)*

Then have students switch roles, so that every student has a chance to see the flashing light of the remote control through the LCD screens of the cameras.

If only one digital camera or camera phone is available, have two students stand on either side of the television. Give one of them the digital camera or camera phone. Tell the student with the phone to look at the remote control through the LCD screen on the camera, while the student without the phone should look directly at the remote. Turn on the television so that sound can be clearly heard. With the students looking at the remote (one with their eyes and the other with the camera), hold down the volume button on the remote. The sound on the TV will increase. Ask the student *without* the camera what he or she observed; the student will have heard the TV get louder but not have seen anything with the remote. Then ask the other student *with* the camera what he or she observed; the student will say that he or she saw a flashing light coming from the remote control. To help settle the dispute about the flashing light, aim the remote at the class and press a button. Students will not see the flashing light. Next, have students in groups look at the viewfinder through the camera while the remote is being activated. They will see the flashing light. A third option would be to hook the digital camera up to the television. This way all students could observe the flashing by looking at the television screen.

Discussion – Pressing for Understanding

Purpose

Engage in a debate as to whether the remote control is emitting light.

Suggested Prompts

- Based on our prior investigations, what is it that our eyes detect?
- What is it that a camera detects? (*Students need to recognize the discrepancy between these two results—our eyes detect light, and a camera detects light, but the camera is detecting something our eyes cannot.)*
- What would provide convincing evidence that what is leaving the remote control is or is not light?

Incorporate ideas such as the following: Our observations with the remote are raising questions about whether all light can be seen by our eyes. On the DQB, group questions related to other kinds of light under the question organizing the final set of investigations: Is There Light We Cannot See?

- Think about the characteristics of light we have identified in our investigations so far—how it behaves, how it interacts with different materials, and the effects it has. What tests might we perform to determine if what is leaving the remote has the same or different characteristics?

  (It is important that students be able to propose three basic tests:

  1. *Testing a blocked/unblocked path—Hold a piece of cardboard between the remote and the TV or between the remote and the digital camera. Try to change the volume of the TV or turn it off and on while a piece of cardboard blocks the path*

between the remote and the TV or have a volunteer describe what they observe in the camera LCD.

2. *Testing whether the signal can be reflected from a mirror—Face the remote away from the TV or the digital camera. Hold the mirror close to the remote, and position the mirror so that it could reflect the remote's rays back to the television or camera. Try to change the volume of the TV or turn it on or off or have a volunteer describe what they observe in the LCD as you change the volume.*
3. *Testing whether the signal can be transmitted through a clear substance—Point the remote at the TV or the digital camera. Hold an overhead transparency or pane of glass one foot from the remote. Try to change the volume of the TV or turn it on or off or have a volunteer describe what they observe in the LCD.)*

- One characteristic of light we identified was that light travels in straight lines unless its path is blocked. How might we test to see if what is leaving the remote behaves the same way?
- Another characteristic we identified was that light is reflected by smooth surfaces like a mirror. How might we test to see if what is leaving the remote interacts in the same way?
- Another characteristic we identified was that light is transmitted by transparent materials. How might we test to see if what is leaving the remote interacts the same way?

List the proposed tests on the board and have students record them on the first column of the table in their activity sheet. Direct students to do the following now that they have proposed some tests: "Make a set of predictions in the middle column of the table on your activity sheet about the results you would predict if the remote is giving off light." Remember, this is not necessarily what you think will happen but what you think would happen if the remote emits light.

Once students have made their predictions, conduct a series of quick demonstrations to test the signal from the remote control in order to determine whether it is light. Before each demonstration, ask students to share their predictions.

It is important that the predictions that students make are based on the premise that the remote is emitting light, not on prior experiences with remote controls. This is an instance in which students are engaging in scientific work—the testing of models by making hypotheses and performing experiments. If in this case, whatever the remote emits acts like light, this provides evidence that the remote may be emitting light. If it does not, it is strong evidence that it is not. In this particular case, you will find that whatever the remote control emits acts like light.

The experiment using the mirror should be tested prior to students attempting this. Many remotes will work by simply scattering the infrared light off of the walls. One way to improve the chances of the remote only working off the mirror (and thus confirming that the remote is emitting light) is to hold the remote pretty close to the mirror. Students may later suggest that scattering would be an additional way of testing this as light, and that experiment should be encouraged.

Suggested Prompts

- Look at the data you collected for each of the tests. In what ways did whatever was leaving the remote act like you predicted light should act? In what ways did it not?
- Based on the data, what evidence do we have that what is leaving the remote is light or not?

(Students may respond that the remote is indeed giving off light that can be seen by the camera but not by their eyes, as it behaves in ways that are similar to light.)

The following activity will introduce a way that can explain why the light leaving the remote is different from the light that you can see with your eyes.

Introducing Homework 12.1 – Is the Remote Emitting Light?

In Homework 12.1, students choose one investigation from Activity Sheet 12.1 and explain why it provided evidence that the remote control signal is light. Students then propose an additional test not used in Activity 12.1 and what evidence this test would provide. This homework provides an opportunity to assess students' understanding of how to use evidence (in this case, textual evidence) to support an idea. As they are asked to propose an additional test and consider the evidence it would provide, the homework provides that opportunity, as well to assess students' understanding of evidence. Use of evidence is key to explanation, argumentation, and modeling, as described in NGSS. Activities such as this support students in building a core understanding of what counts as appropriate and sufficient evidence in science, an understanding foundational to scientific practice and throughout IQWST.

Materials – Activity 12.2

For the Teacher

- (1) projector*
- (1) transparent baking pan or casserole dish with about ½in of water*
- PI: Waves
- PI: Rainbow
- PI: Wavelength
- (1) computer with Internet access connected to speakers* (It may be helpful to bookmark the following site for easy access during class: http://www.audionotch.com/app/tune/)
- You will want to follow this link to the sine-tone generator and try it out on your computer before using it with students.
- Bookmark the following site for easy access during class http://www.falstad.com/ripple. If you need to download JAVA, have the computer administrator do so before the lesson.

For Each Student

- Activity Sheet 12.2

*This item is not included in the kit.

Activity 12.2 – Introducing the Wave Model

Discussion – Synthesizing

Purpose

Understand the difference between visible and nonvisible light.

Suggested Prompt

- Look at the drawings of our consensus model of how light helps us see. How does the model account for our observation that what is emitted by the remote behaves like light but we cannot see it? *(It is important that students recognize that they cannot explain why they see some light and not other light using the current consensus model.)*

Detecting Sound

Incorporate ideas such as the following: As we have seen in our investigations so far, to be useful, models often change to reflect growth in our knowledge based on new evidence. We have discovered a new phenomenon that our model cannot currently account for, and we will need to do further investigations to revise it.

- What are some other examples of things that you know are present but your senses cannot detect? *(Students may respond that they cannot hear dog whistles, or smell as pets can.)*

Incorporate ideas such as the following: Hearing is a sense, which can detect some sounds and not others. Humans are only capable of hearing a certain range of pitches. We will explore this phenomenon using a frequency generator that is available online—it creates sounds from very low to very high pitches.

A free web-based generator can be found at the following site: http://www.audionotch.com/app/tune.

Turn up the volume on your computer so that everyone can hear the tone. Tell students: "I am going to start out by increasing the pitch from a middle point to very high. Raise your hand when you can no longer hear the tone."

Start at about 4,000Hz and begin increasing the frequency. Some students will squirm and complain the tone is irritating. They are right! After about 14,000Hz, students will start raising their hands that they can no longer hear the tone.

Tell students: "I am going to start out by decreasing the pitch from a middle point to very low. Raise your hand when you can no longer hear the tone."

Return to 4,000Hz and decrease the pitch until you reach 100Hz. Students should be able to hear the tone in this entire range of pitches.

- Not everyone's hand went up at the same time. Why do you think that was? *(Not everyone hears exactly the same range of pitches.)*
- Are there sounds you cannot hear? Why do you think so? *(Yes. For example, dogs react to hearing a dog whistle blown, but the pitch is above the range of human ears.)*

Explain the following: The range of pitches that we can hear, and the pitches that are too high or too low, provide one comparison to help us think about light that we cannot see. Next, we will use another example to help us think about the model of seeing in order to explain the difference between visible and nonvisible light.

Waves in Water

Project the simulation from the following website: http://www.falstad.com/ripple and activate JAVA if requested to do so.

- Imagine this simulation is showing a pond of water with our finger tapping the pond at the top at a constant rate. The tapping makes water waves that move away from the finger. How are this situation and our model of how light behaves similar? *(One important comparison is that both the waves in the pond and light move outward from the source.)*

Hold a yardstick on the screen so that one end of it aligns with the source of the waves and the other end is in any direction. This means that the yardstick goes radially away from the source.

- In which direction do the waves move? *(It is important that students notice that the waves seem to move along the yardstick, regardless of the direction of the yardstick, so long as it is along a radius leaving the source.)*

To reinforce this, display PI: Waves, which shows an image of waves with radial arrows imposed on it.

Explain the following: In the simulation, your finger is a source of water waves, and the water waves move away from your finger in straight lines. Imagine that instead of a simulation of water waves, the simulation shows how light is radiated. A light source makes light waves that move away from the source, just as water waves move away from their source. Similar to waves in water, light travels from place to place as a wave. Remember that in the light model we developed earlier in the unit, the light from the light source spreads out from the light source in all directions. The difference is that water waves spread out on a flat surface, like a pond, while light waves spread out in all direction, including up and down.

Using a ruler, measure the radial distance between two of the adjacent white circles on PI: Waves. Pick another two adjacent circles and verify for students that this the radial distance between them is the same.

Explain the following: Scientists call the distance between two waves the *wavelength*. Pay attention to what happens to the wavelength in the pan when we tap faster or slower.

Return to the simulation of the water waves and, using the slider called Source Frequency, make the tapping occur faster or slower. Notice that the faster the tapping frequency, the smaller the distance between the waves (the wavelength), and vice-versa—the slower the tapping frequency, the larger the wavelength.

Light Waves

Incorporate ideas such as the following: Unlike water waves, which move slowly, light waves move very fast, at the speed of light! Your eyes cannot detect that they are actually detecting a wave. When you see an object, your eye is detecting the light waves that travel from that object to your eye. If there is a blocked path between an object and your eye, you cannot see it because no light waves can reach your eye. The wavelengths of light waves can range from the very, very tiny, many millions of times smaller than the width of a human hair, to very huge, larger than Earth's diameter. Your eye can only detect a very small range of these wavelengths, and scientists call this range of wavelengths that you can detect visible light.

Direct students to discuss their ideas with the person next to them and write down the answer they agree upon. Request a few volunteers to share their ideas with the class.

Thinking about what we just learned about our ability to see a range of wavelengths of light, why do you think our eyes could not see the light from the remote control, but a camera could? *(It is important that students realize that the camera can detect a wider range of wavelengths than their eyes. Although the camera is designed to detect a range of wavelengths that is similar to the eye, it also detects some light that is just outside of their visible range. If our eyes were capable of detecting this wavelength of light, we would see the remote flashing, too.)*

Incorporate ideas such as the following: The visible light that we can see can appear as many different colors.

Display PI: Rainbow. What colors do you notice on the edge of the rainbow? *(It is important that students notice that they are red and violet.)*

When a rainbow forms, the water droplets in the air are separating light into the different colors of which it is made. The colors separate based on their wavelengths with the shortest wavelength at one end (violet) and the longest wavelength at the other (red).

Display PI: Wavelength, which contains a picture of the visible spectrum.

This is representation of the visible spectrum—the range of light wavelengths that we can see. Notice that violet light is on one side with the shortest wavelength and red light is on the other with the largest wavelength. Colors in between are arranged from lowest to highest wavelength. Point to just outside the red side of the visible spectrum.

The light from the remote control is not visible because its wavelength is a little bit longer than red light. Scientists call this kind of light infrared light, and this is the kind of light that remote controls emit.

Let us use this way of thinking about light as waves to explain some of what we have observed.

- According to the wave model of light, what makes blue light different from green light? *(The difference between the types and colors of light is that they have different wavelengths. Blue light has a shorter wavelength than green light.)*
- How does red light compare with the infrared light that comes from the remote? (*They are both types of light, but our eyes can detect red light and cannot detect infrared light. IR has a longer wavelength than red light.)*
- How is visible light different from nonvisible light? (*The difference between visible and nonvisible light is that human eyes are sensitive to a specific range of wavelengths that humans can see. That range is called visible. Everything else is called nonvisible light.)*

Wrapping Up the Lesson

Thinking about our question for the investigation (Is There Light We Cannot See?), what new ideas have we developed that help us answer the question? *(It is important that students be able to explain that there is light we cannot see, and the reason we cannot see this light is because its wavelength is too long for our eyes to detect. They have also learned that different wavelengths of visible light appear to our eyes as different colors.)*

Add the following principles to the list of Scientific Principles and have students do the same in their Student Guides:

- There are many different wavelengths of light. Most of these cannot be seen.
- Different wavelengths of visible light appear to us as different colors.

Note: In the next lesson, you will investigate how the world might look to you if you were able to see a wider range of wavelengths of light.

Introducing Reading 12.1 – Infrared Light

The reading describes the connection between temperature, different colors of light, and the wavelengths of light that human eyes can sense. The reading also addresses uses for infrared light including in everyday life.

You might light a candle and ask a volunteer or two to describe the colors they can see when looking closely. Ask: "Why do you think the flame has different colors? You might also ask: How can you tell if something is hot without burning yourself even if it does not look hot?"

Tell students that you would like them to come to the next class ready to describe one way that infrared light is used, and how understanding infrared light is important for this process. This is one way to bridge the two lessons.

LESSON 13

Ultraviolet Light and Nonvisible Light Imagery

PREPARATION

Teacher Background Knowledge

Prefixes for Nonvisible Light

The frequency and wavelength of light have an inverse relationship, meaning that large wavelengths have a low frequency and vice versa. The prefixes ultra- and infra- were given to ultraviolet and infrared to describe the proximity of their frequency to the visible range of wavelengths. The *ultra* (meaning above or beyond) in ultraviolet refers to the fact that this light has a higher frequency (and thus a lower wavelength) than visible light. On the other hand *infra* (meaning below) denotes that infrared light has a lower frequency (and thus a higher wavelength) than visible light.

Because these prefixes are assigned based on the reverse of what students experience in this unit, it is best to refrain from including this information during formal instruction.

Percentages

This activity assumes that students have developed some elementary understanding of percentages. For example, they would understand that the fraction ½ would be equal to 50% or that ¼ would be equal to 25%. It does not, however, assume proficiency in calculating the percent loss of a quantity. If you would like to use a more quantitative approach, you might have students set up data tables, calculate the percentage reduction in the ultraviolet light transmission caused by applying the sunscreen to the window, and then calculate the percentage reduction in the visible light transmission caused by the sunscreen. The rest of the activity as written, however, will not require students to make precise calculations.

UV Sensors

The Pasco UV sensor uses a silicon photodiode, which is a device that produces a voltage when ultraviolet (UV) light hits it that is proportional to the intensity of the UV light. It is difficult to get a UV sensor to measure in absolute units without a source of known UV light, so the number reported by the sensor is a relative value, meaning that this value is not calibrated to any real units. Therefore, the probe is useful to compare the amount of UV coming from different sources, not to determine an absolute value of UV coming from one source. If the value reported by the probe doubles, this is an indication that twice the UV light is hitting the probe compared to before.

Using a Control

In this case, it is important to use a control square without sunscreen, because it ensures that the sunlight passing through each square is as equivalent as possible. If you simply took a measurement before and after applying sunscreen to one area of the window, it is possible for the sunlight hitting the detector to have changed in some way (due to cloud movement, Earth's rotation, etc.) during the time elapsed between the measurements. A control square ensures maximum equivalence, and it enables easily going back and forth between sunscreen/no sunscreen conditions.

How Sunscreen Works

Physicists have divided ultraviolet light into the smaller bands called UVA, UVB, and UVC. These types of light can be harmful to humans, because they have a shorter wavelength, and are therefore more energetic than visible light. This more energetic light is able to break the chemical bonds in a skin cell's DNA. Of the three bands, UVC has the highest energy, but this type of light is almost totally absorbed by the atmosphere and never reaches the ground. UVB has the next highest energy and has been linked to most skin problems related to sun exposure, including sunburn and skin cancer. UVA is the lowest energy ultraviolet light and is less harmful, but a growing body of evidence suggests that it is also associated with the deleterious effects of prolonged sun exposure.

Clear sunscreens contain a molecule that absorbs ultraviolet light. The first and most widely used of such molecules is called para-aminobenzoic acid (PABA), which absorbs UVB light. When the UVB light is absorbed, it delivers energy to the sunscreen, and this energy is soon re-radiated as IR light. PABA can cause an allergic reaction in some people and does not absorb UVA radiation, so a variety of other chemicals are used in sunscreen as well. All sunscreens are designated with a particular sun protection factor (SPF), and this number is a measure of how much UVB light a particular sunscreen blocks in laboratory tests. An SPF of 10 means that about 90% of UVB is blocked, whereas an SPF of 60 blocks about 98% of UVB. Typical skin has a natural defense against UVB light, and the SPF number is a rough estimate of how many times this natural protection a sunscreen provides. Typical fair skin has an SPF of 1, and an SPF of 15 affords roughly 15 times the natural protection. The SPF of a sunscreen is based only upon UVB absorption not UVA.

A UV detector is designed to detect UVA radiation, and most sunscreens absorb less UVA light than they do UVB. Therefore, even sunscreens with a very high SPF (remember, this is only based on UVB absorption) may let a relatively high fraction of UVA light through. To achieve a higher level of UVA absorption, be sure to use a sunscreen that is designated as broad spectrum or specifically blocks UVA and UVB light.

Infrared Light and Cameras

Physicists have divided infrared light into smaller bands called near infrared and far infrared, named for how far their wavelength is from the visible part of the electromagnetic spectrum. Remote controls emit light in the near infrared, but warm objects emit light in the far infrared. Digital cameras can only detect light in the near infrared, so it cannot detect the IR light given off by warm objects. If you were to take a normal digital camera into a completely dark room, you would see nothing, but a thermal imager in a dark room would be able to detect the light given off by objects in the far infrared.

Setup

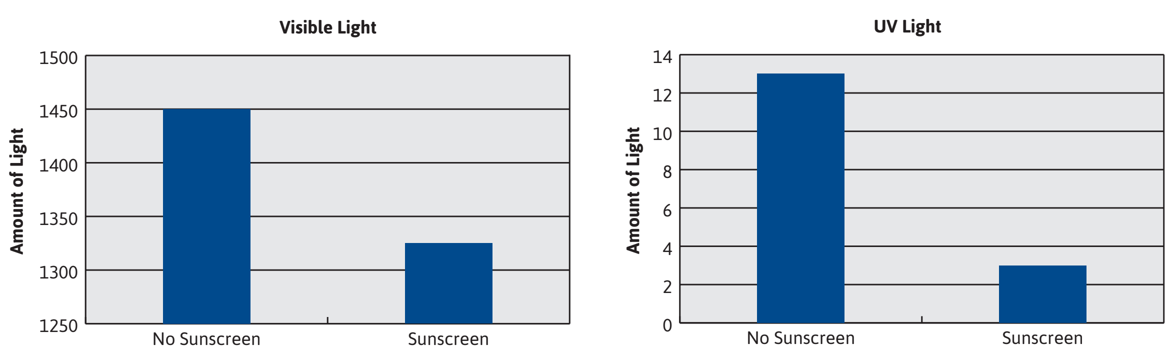
In Activity 13.2, a video of IR imagery or Infrared imagery would be helpful for students as a visual aid to help them experience what the light actually looks like as emitted.

⚠ Safety Guidelines

Refer to IQWST Overview.

Differentiation Opportunities

1. Students may be interested in evaluating claims made by sunglasses in regard to UV protection. You may want to test the claims in a similar fashion by using a pair of sunglasses rather than sun block. Dark sunglasses may transmit as little as 2% of the visible light that hits them, so it is a good idea to try this ahead of time to be sure that there is a significant difference between the amount of UV and visible light transmitted for these glasses.
2. A bar graph may help students to make sense out of the percentages that they calculated and to help compare the fraction of decrease in the visible light to that for the UV. The bar graphs should look something like these:



3. The last page of student materials references the role of the ozone layer on Earth. Students may wish to pursue (or you may wish to assign) additional exploration of this topic.

Lesson 13

Ultraviolet Light and Nonvisible Light Imagery

TEACHING THE LESSON

Performance Expectation

Students will analyze and interpret mathematical, graphic, and observational data and use that as evidence to argue that the wavelength of light determines whether it is absorbed by a particular material.

Overview

Activity 13.1

Investigate the amount of visible and UV light that passes through glass coated with sunscreen.

Activity 13.2

- Analyze data using percentages and bar graphs to interpret trends.
- View images of infrared and ultraviolet light to explore light the eyes cannot see.

Building Coherence

Students revisit the ideas of absorption and transmission from Lessons 7 and 8 and what they learned about filters (Lesson 10) to investigate materials that may be transparent for visible light but opaque to nonvisible light or vice versa. Students also examine how the world may look different to them if they could see UV and/or IR light.

Timeframe

2 Class Periods

Safety Guidelines

These activities involve sunlight and images of the sun. Students should be reminded that looking at the sun for any length of time can be very damaging to their eyes.

Introducing the Lesson

Reading Follow Up

- What was one of the uses of infrared light that you read about? How did it make use of infrared light? *(We read about IR cameras to take pictures of objects in space, IR goggles to see where there is not much visible light, and IR sensors to measure oxygen in the blood.)*
- What evidence did Herschel use to claim that infrared light exists and produces heat? *(Herschel shone the spectrum across several thermometers, and a thermometer*

placed past the red end increased in temperature the most, suggesting there was invisible light present that produced more heat than visible light.)

- If there is infrared light with a longer wavelength than we can see at the red end of the spectrum, what could this lead us to predict about the other end of the spectrum? *(There could also be light with a shorter wavelength than we can see at the other end, past violet.)*

Ask: "What ideas and evidence do we have that are related to the question: Is There Light that I Cannot See?" *(Students could not see the infrared light that came from the remote because its wavelength is longer than they can see, but they could detect it using the digital camera. They have evidence that it is light because it behaves similarly to visible light based on several tests.)*

Materials – Activity 13.1

For the Teacher
- PI: Wavelength
- sensor UVA of non–UV protective glass*

For Each Student
- Activity Sheet 13.1

*This item is not included in the kit.

Activity 13.1 – Investigating UV Light

Using the masking tape, make two 6-inch squares next to one another on a window. Use a visible light detector and take readings in the middle of each square. The readings should be about the same. If not, then move the squares to a location on the windows where you get equal readings.

> Note: Some schools use glass windows that have a special UV coating. You can test this by pointing the UV sensor through your classroom windows at the sun. If the measurement is zero, or close to zero, you need to either open the window or go outside and use a pane of non–UV protective glass.

What are some situations where you have seen or heard reference to UV or ultraviolet light? *(UV-blocking sunglasses or sunscreens; UV light is dangerous.)* If questions arise about UV, add them to the question parking lot on the DQB until the end of Lesson 13.

Like infrared light, UV light has a wavelength outside the range of wavelengths visible to humans, IR light has a wavelength that is too long to be seen, and UV light has a wavelength that is too short!

Use PI: Wavelength to show the position of both IR light and UV light in relation to the visible spectrum. Ask: "Where are infrared and ultraviolet light in relation to the colors of light that we can see?" *(It is important that students notice that ultraviolet is just outside the visible range past violet light and that infrared is just outside the visible range past the red light.)*

In this activity, you will be helping students understand that UV light may interact with some materials differently than visible light. Just as a color filter absorbs some wavelengths but not others, sunscreen is designed to absorb UV but not visible light. In this activity, students should experience that it is possible for material to be transparent for visible light but opaque for UV light.

Ask: "What do you know at this point about sunscreen and how it works?" Repeat the activity you did in the Preparing Activity 13.1 in front of the students. We measured similar light readings through each square; what do the similar readings tell us about the window and the light? *(It is important that students be able to explain that it means that a similar amount of light is transmitted through the window and going into the light detector in each square.)*

Show the UV detector to students. Explain that this an ultraviolet light detector. It works like the visible light sensors that we used in our previous investigations, except that rather than detecting light in the visible wavelength, the UV detector detects the amount of light with a wavelength shorter than visible light.

Hold the UV detector in the two window squares—once again, the readings should be similar.

We also measured similar UV readings through each square; what do these readings tell us about UV light and the window? *(It is important that students be able to explain that the similar values mean the same amount of UV is entering the detector through the window in both squares.)*

Exploring Sun Block

Apply a layer of sun block to one of the window squares. Try to spray an even layer of sun block within the square. Ask: "Why do you think it is important to have one square with sunscreen and an identical square without sunscreen?" (*We need something to which to compare the square with sunscreen, so that we know that there was not something else happening like a change in the light itself.)*

Students may not be accustomed to reasoning about the need for a controlled experiment, so they may have difficulty coming up with the answer. Nevertheless, it is useful for them to think about reasons why a science experiment should be set up like this. If students do not recognize the value of a control window square, introduce the idea. We set up two squares, one with sun block and one without, to test what effect the sunscreen has on the light passing through the window. The only difference between the two squares is that I have applied sunscreen to one of them. Therefore, any differences in the light reading between the two squares must be because of the presence of sunscreen on one square.

Using the UV detector, take an initial reading in the square without the sun block and have students record this value in Line 1. Depending on the time of day, season, weather, and angle of the window, this reading will vary greatly. It will be likely, however, somewhere between 5 and 20 using a detector.

After discussing, record the students' consensus responses to the following questions in a visible place.

- If this sun block blocks all of the UV light (blocks 100%), what value will you get when you take a reading in the square with sun block? *(about 0)*
- If this sun block does an OK job of blocking UV light (blocks about 50%), what value will you get when you take a reading in the square with the sun block? *(about ½ the initial reading)*
- If the sun block only blocks some of the UV light (blocks about 25%), about what value will you get when you take a reading in the square with the sun block? (about ¾ *the initial reading)*
- If this sun block does a good job of blocking UV light (blocks about 75%), what value will you get when you take a reading in the square with the sun block? *(about ¼ the initial reading)*
- If the sun block does not block any of the UV light (blocks about 0%), about what value will you get when you take a reading in the square with the sun block? *(same as the initial reading)*

Record each of the values from a–e on the board in a table such as the following.

	UV DETECTOR READING
Measurement without sunscreen	13
Sunscreen block 25% of UV	9.75
Sunscreen block 50% of UV	6.5
Sunscreen block 75% of UV	3.25
Sunscreen block 100% of UV	0

Take the reading with the UV detector in the square with the sun block and have students record the value on Line 3 of their Activity Sheet. Depending on the sun block used and the way that you applied it, the sun block will block between 50% and 100% of the UV light.

- Based on the values that we predicted, about how much of the UV was blocked by the sun block? (*Answers will depend on the initial reading.)*
- Based on our results, do you think the sun block is doing a good job of blocking the UV light? (*Answers will vary; it is only important that students give a rationale for their position.)*
- We know that the sun block is blocking some of the UV light; how might we test whether it is blocking visible light as well? (S*tudents may propose that you repeat the same procedure with the visible light detector instead of the UV detector.)*

Because the readings from the light detector will be of a different higher magnitude than the UV detector (around 100 lux), it will be necessary to repeat a series of questions similar to the ones for the UV detector. For example, you would not want students to think that a drop in 10 units means the same thing for both detectors. Instead, you will want students to estimate the percentage drop as a fair way to compare.

Begin by taking a reading from the visible light detector in the square without sunscreen. Have students record this value in Line 4 of the activity sheet.

Repeat the questions that were asked about UV light and again record the responses. Discuss the following questions with students:

- If this sun block blocks all of the visible light (blocks 100%), what value will you get when you take a reading in the square with sun block? *(about 0)*
- If this sun block does an OK job of blocking visible light (blocks about 50%), what value will you get when you take a reading in the square with the sun block? (*about ½ the initial reading)*
- If this sun block does a good job of blocking visible light (about 75%), what value will you get when you take a reading in the square with the sun block? *(about ¼ the initial reading)*
- If the sun block only blocks some of the visible light (about 25%), about what value will you get when you take a reading in the square with the sun block? *(about ¾ the initial reading)*
- If the sun block does not block any of the visible light (blocks 0%), about what value will you get when you take a reading in the square with the sun block? *(about the initial reading)*

Record these values on the board to serve as a reference.

If the sun block blocks visible light in the same percentage as the UV light, then what will the reading be when you take a reading in the square with the sun block? (*It is important that students make estimates that reflect a similar percentage [between 50 and 100%] of the visible light being blocked.)*

Have students record this value on Line 5 of their Activity Sheet. Now take the readings in the square with the sun block.

- Based on the values we predicted, what percentage of the visible light was blocked by the sun block? Record this value in Line 6 of your Activity Sheet. (*Depending on the sun block used and how it is applied, only about 10 to 25% of the visible light will be blocked. This value will be quite different than what they recorded in Line 5 of the activity sheet.)*
- What can we conclude about the kinds of light sun block blocks most effectively? *(It is important that students conclude that the sun block blocks UV light much more than it blocks visible light.)*
- Why would companies want their sunscreen to absorb nearly all the UV light that hits it but none of the visible light? *(UV light can be damaging to the skin, so the*

sunscreen makers want sunscreen to absorb all of the UV so that none of it reaches the skin. They do not want to absorb the visible light because then sunscreen would not be clear—people would look like they were painted.)

- What would sunscreen look like if it absorbed all of the visible light that hit it? *(If sunscreen absorbed all of the visible and the UV light, it would look black because it would scatter no light back to our eyes.)*
- Based on what we have learned from today's investigation, how is sun block similar and different from the color filters we used previously in the unit?

✓ Ask: "How is the sun block similar to the filters we used previously in the unit?" *(The filters absorb some wavelengths but let others pass through, and this is what the sunscreen does as well.)*

Introducing Homework 13.1 – UV Light and UV/IR Imagery

This homework provides an opportunity for students to evaluate a sunglass manufacturer's claims as they interpret graphs representing the amount of visible, UV, and IR light transmitted by sunglasses. This homework provides an opportunity for students to extend and apply their understanding to a real-world example outside of science class. As such, it is an opportunity for formative assessment of their understanding of UV and IR light, and transmission.

Introducing Reading 13.1 – Nonvisible Light

Students have learned that there are two types of light that they cannot see. The reading introduces additional nonvisible types of light beyond IR and UV light: radio waves, microwaves, and x-rays. Ask: "What do you think x-rays have to do with what we have been studying? How about microwaves?" Students should be prepared to discuss what cell phones and microwaves have in common.

Materials – Activity 13.2

For the Teacher
- PI: Sun with Camera Lens
- PI: Sun with UV Camera
- PI: Sun with Infrared Camera
- PI: Flowers
- PI: Infrared Photography

For Each Student
- Activity Sheet 13.2

Activity 13.2 – How Would the World Look if People Could See UV and IR Light?

Reading Follow Up

Ask: "What do cell phones and microwaves have in common? How would the world look different to us if our eyes were sensitive to x-rays instead of visible light waves?"

Our investigation measuring light coming through the window provided evidence that the sun emits UV light. We also found that it is possible to design a substance that blocks UV light but lets most visible light through. What investigations showed us that the same can be true of colored light? (*Students used colored filters to allow some colors of light to pass through while blocking others. Based on the last several activities, they know that these filters were allowing some wavelengths of visible light to be transmitted or scattered while absorbing the others.)*

Scientists can also design filters that allow UV light through (transmission) while blocking (absorbing) visible light.

Display PI: Sun with Camera Lens, which shows how the sun looks when photographed with a normal camera that is designed to detect visible light. This image shows the sun when photographed with a camera that detects visible light. Remember, you should avoid ever looking at the sun directly, because you can permanently damage your eyes.

Display PI: Sun with UV Camera, which shows a picture of the sun taken by a special camera that is only designed to detect ultraviolet light and nothing else. This second image also shows the sun, this time photographed with a camera that detects UV light. While we cannot see UV normally, this image shows violet color wherever UV light was detected by the camera.

Display PI: Sun with Infrared Camera, which shows a picture of the sun taken by a special camera designed to detect only infrared light and nothing else. This image shows the sun again using a camera that detects IR light.

How can pictures of the sun taken with cameras designed to detect nonvisible wavelengths help us learn more about the sun? (*These pictures can reveal more information about the sun than we would have making observations with our senses.)*

Scientists have designed a camera that detects only UV light and does not detect any of the visible light that people normally see; this way they can see interesting things that they may have ordinarily missed. Here are some examples of images taken with a UV camera. Display PI: Flowers, which shows images of flowers that were taken with a UV camera.

Scientists have also designed a special camera to detect IR light. As we noticed with the remote, it turns out that most digital cameras detect a small amount of IR light that has a wavelength that is just barely too long for humans to see. This is really just an accident—a digital camera is designed to replicate what people see with their eyes, and people usually do not notice a difference between what they see and what the digital camera shows them, because the range of wavelengths detected by their eyes and the range detected by the digital camera are very close, but the range detected by the digital camera is a little bigger. We noticed this difference when we saw that a digital camera could detect the light coming from a remote but our eyes could not.

Some cameras are specially designed to detect only IR light and no visible light. This is an image taken with an IR camera.

Display PI: Infrared Photography. Ask: "Which objects are the brightest in these photos?" (*The brightest objects or parts of objects in the photos are those that are the warmest.)* "If warmer objects emit more IR light than colder objects, even in conditions with little or no visible light, why might IR detectors be useful to firefighters or astronomers in their work? What about UV detectors? Record your ideas on your activity sheets."

After students have written their ideas about how IR detectors are useful to firefighters and astronomers, if you can locate a video—perhaps searching for video of "IR imagery"—this would be a good point at which to show and discuss.

Imagine that one night during a power outage, all the lights in the city go out. Ask: "If you had a choice of using a UV or an IR camera to help you see, which one would you choose? Explain your ideas." (*Everything emits IR light, so there would be plenty available to detect, but UV light is only emitted from really hot objects.)*

Sometimes infrared radiation and infrared light are used interchangeably.

Wrapping Up the Lesson

Have students in groups consider the Driving Question—Can I Believe My Eyes?—by discussing what we have learned about light that is outside of our visible range and how that information helps us think about times when our eyes do not provide all of the information. Do not worry about finding a right answer—this is a chance for you to brainstorm some ideas. Have students record some thoughts. Then ask questions such as the following:

- How do detectors like the digital camera and the UV detector provide evidence about situations where our eyes might not provide all the information?
- Why might it be important to know about UV or IR light if we cannot use those wavelengths to see?
- How did the model of seeing help us figure out that there was light you could not see?

Introducing Homework 13.2 – UV Light and UV/IR Imagery

For Question #1, students interpret evidence from an IR photograph to determine whether a car was recently driven. For Question #2, students need to use what they know about absorption and reflection. This homework provides an opportunity to assess students' application of the ideas they have learned to two real-world situations.

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