EngrTEAMS

EngrTEAMS: Engineering to Transform the Education of Analysis, Measurement, and Science in a Team-Based Targeted Mathematics-Science Partnership

Laser Security System

Grades 6-8

University of Minnesota
STEM Education Center
NSF
INSPIRE Research Institute for Pre-College Engineering
Purdue University

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About EngrTEAMS

Purpose

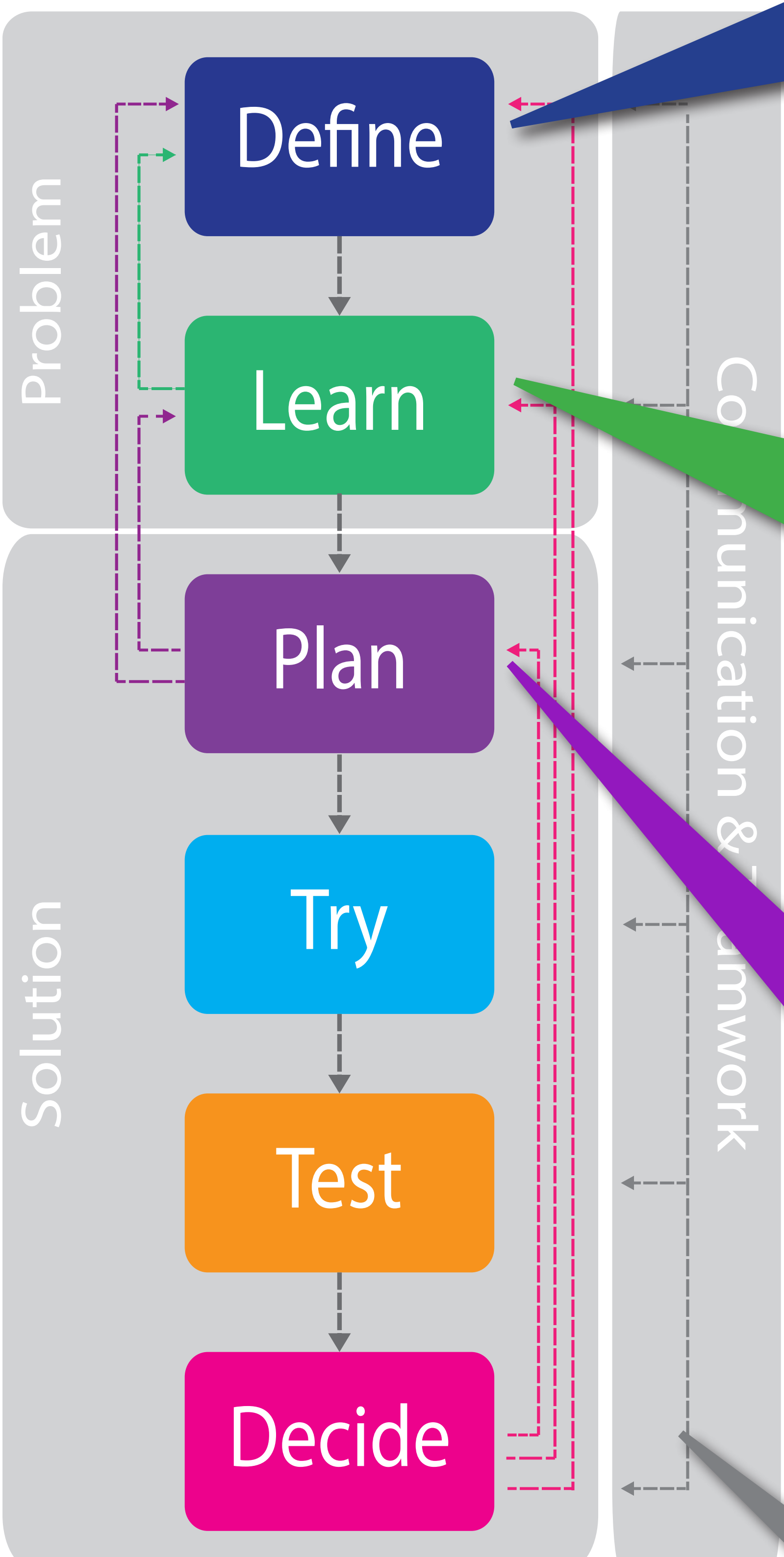
The project is designed to help 200+ teachers develop engineering design-based curricular units for each of the major science topic areas within the Next Generation Science Standards, as well as data analysis and measurement standards for grades 4-8.

With a focus on vertical alignment and transition from upper elementary to middle-level, this project will impact at least 15,000 students over the life of the grant.

To learn more about the project and find additional curricular units go to www.engrteams.org.

Overview: Engineering Design Process

Engineering Design Process
A way to improve



DEFINE THE PROBLEM

- Who is the **client**?
- What does the client need?
- Why does the client need it?
- Who is the **end user**?
- Why might the end user want it?
- What are the **criteria** (requirements) and **constraints** (limits) of the solution?

Problem Scoping:
WHO needs **WHAT** because **WHY**

LEARN ABOUT THE PROBLEM

- What kind of background knowledge is needed?
  - What science/math knowledge will be needed?
  - What materials will be needed?
- What has already been done to solve the problem?
- What products fill a similar need?
- How should we measure success and improvement?

PLAN A SOLUTION

- Continue to specify the criteria/ constraints
- Generate ideas of possible solutions
- Develop multiple solution paths
- Consider **constraints, criteria**, and **trade-offs** (criteria that compete with one another)
- Choose a solution to try
- Develop plans (blueprints, schematics, cost sheets, storyboards, notebook pages, etc.)

COMMUNICATION

- Communicate the solution clearly and make sure it is easily understandable
- Use **evidence** to support why the client should use your solution

Overview: Engineering Design Process

TRY A SOLUTION

- Put the plan into action
- Consider risks and how to optimize work
- Use criteria/constraints and consider trade-offs from the problem/plan to build a **prototype** (a testable representation of a solution), **model**, or **product**

TEST A SOLUTION

- Consider testable questions or hypotheses
- Develop experiments or rubrics to determine if the solution is meeting the stated criteria, constraints, and needs
- Collect and analyze data

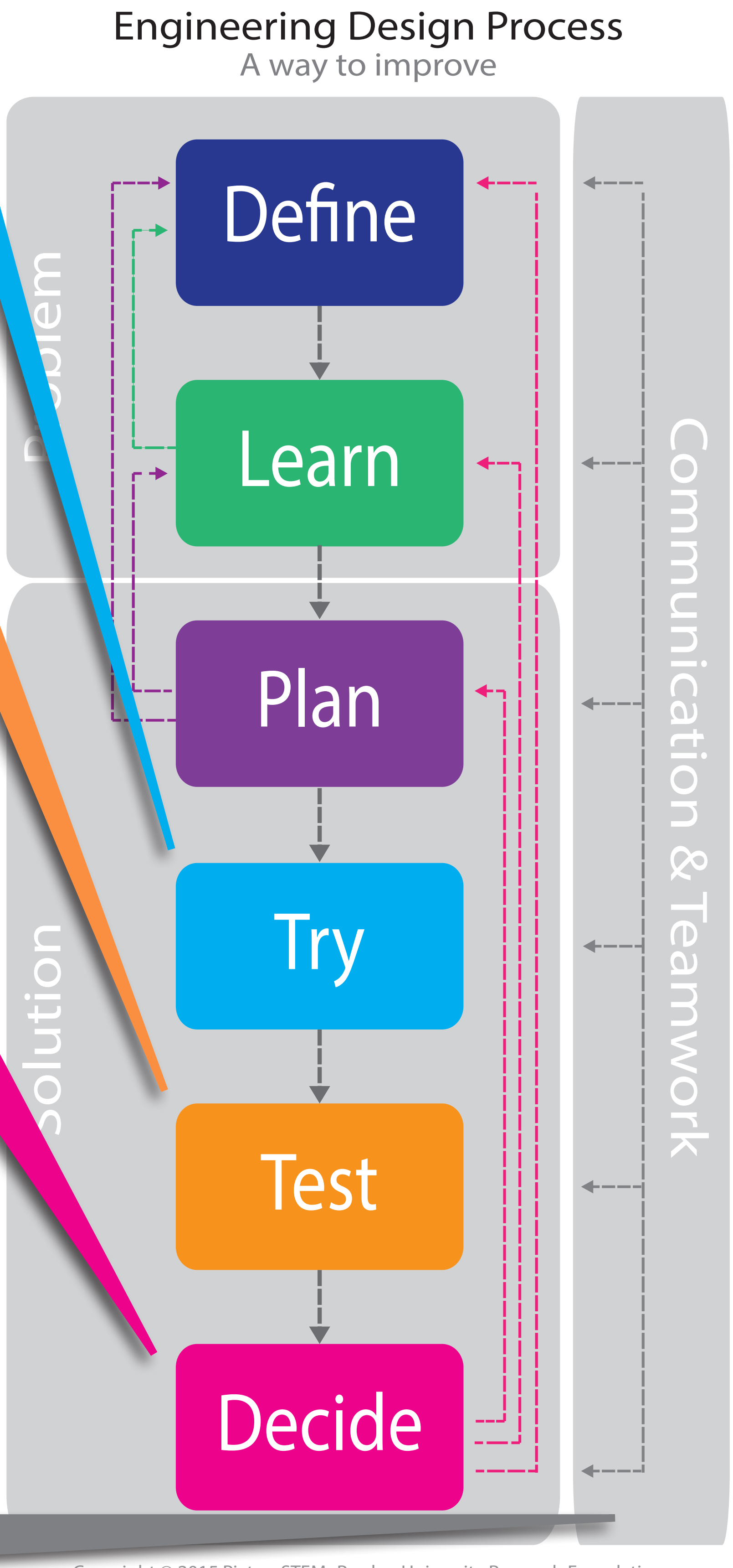
DECIDE IF THE SOLUTION IS GOOD ENOUGH

- Are users able to use the design to help with the problem?
- Does the design meet the criteria and constraints?
- How could the design be improved based on test results and feedback from the client/user?

Iterative nature of design: Always consider which step should be next!

TEAMWORK

- Discuss in teams how the solution meets the criteria and needs of the client
- Consider different viewpoints from each teammate



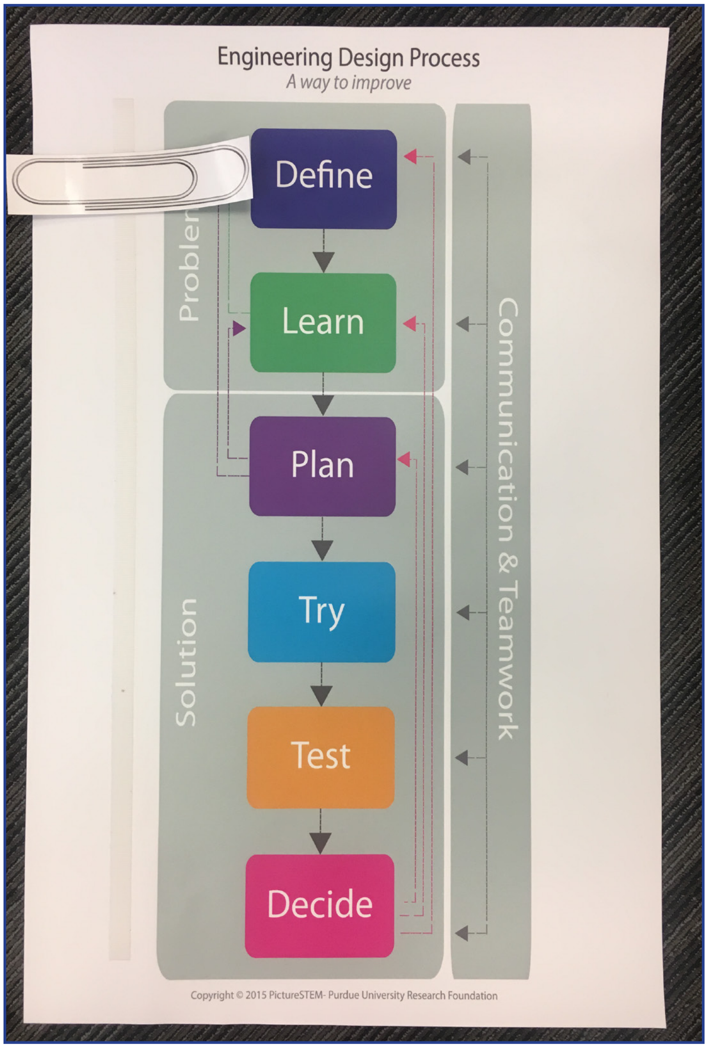
Overview: How to make EDP sliders

HOW TO CREATE THE POSTER

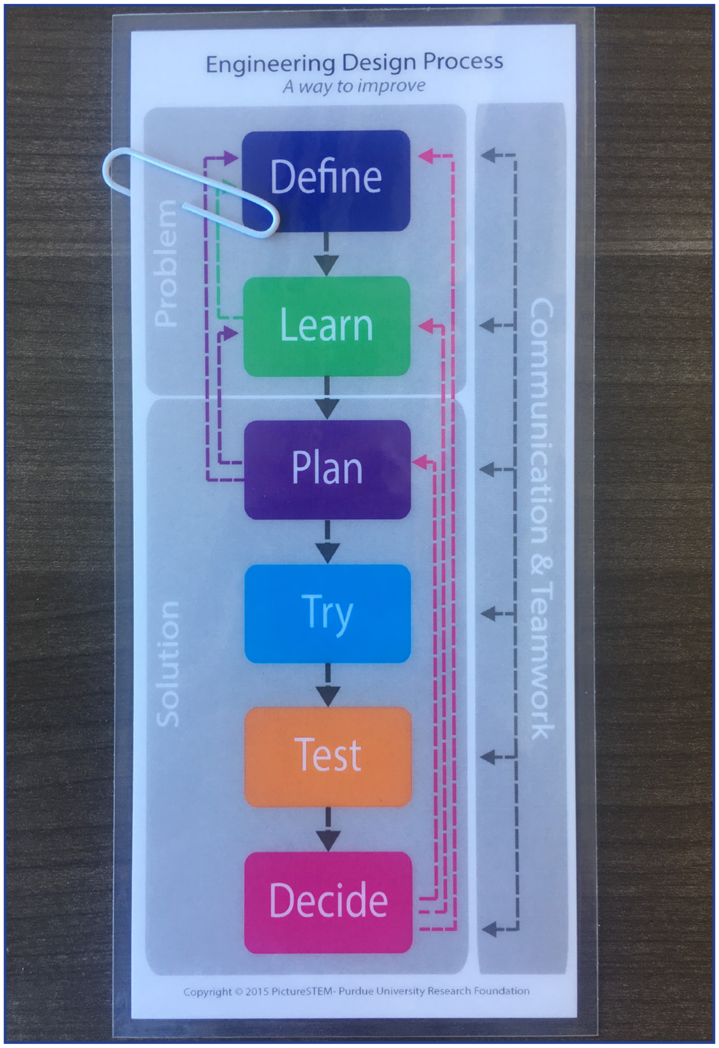
1. Download the high-quality PictureSTEM Slider Poster and the paper clip images from PictureSTEM.org.
2. Print the poster and the paper clip on poster-sized paper and cut to size. High-gloss or semi-gloss paper is the best choice.
3. Use self-sticking Velcro on the back of the paper clip and down the side of the poster so that the paper clip can be placed to point at all 6 sections of the slider.

HOW TO CREATE INDIVIDUAL SLIDERS

1. Print the sliders on the opposite page - enough for one slider per student in your class.
2. Cut the sliders apart.
3. Laminate the sliders individually.
4. Use a jumbo paper clip as the pointer for each slider.

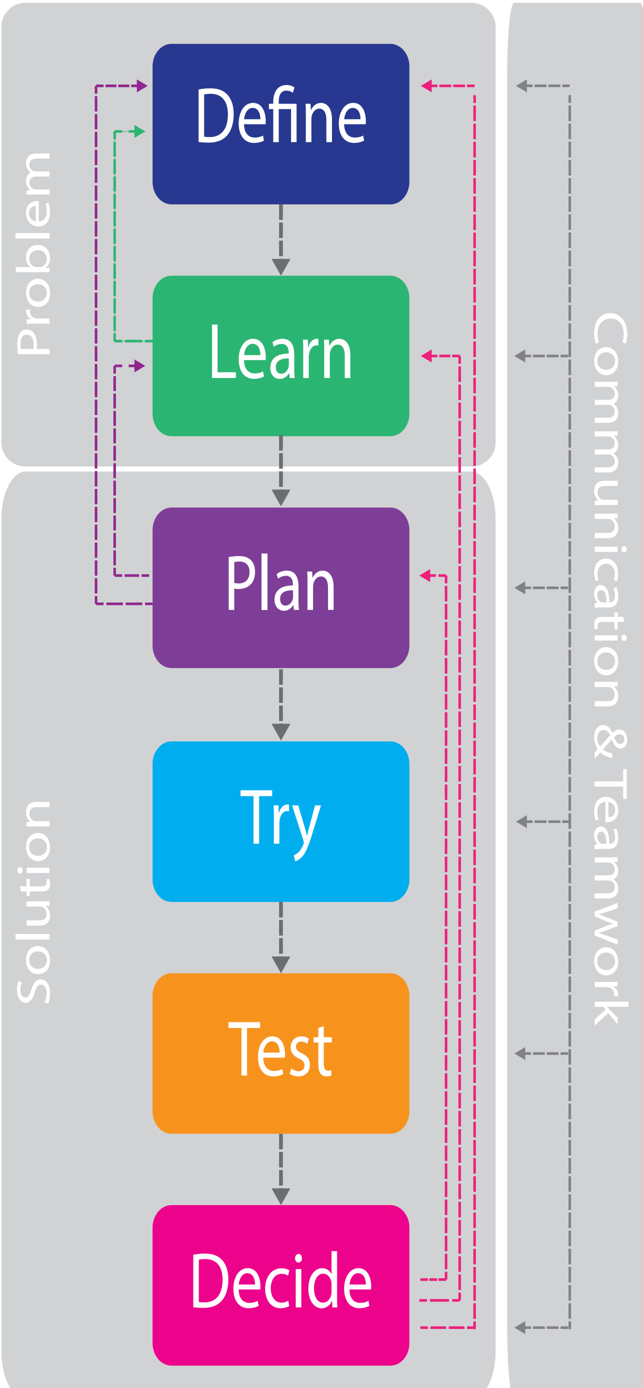


Poster

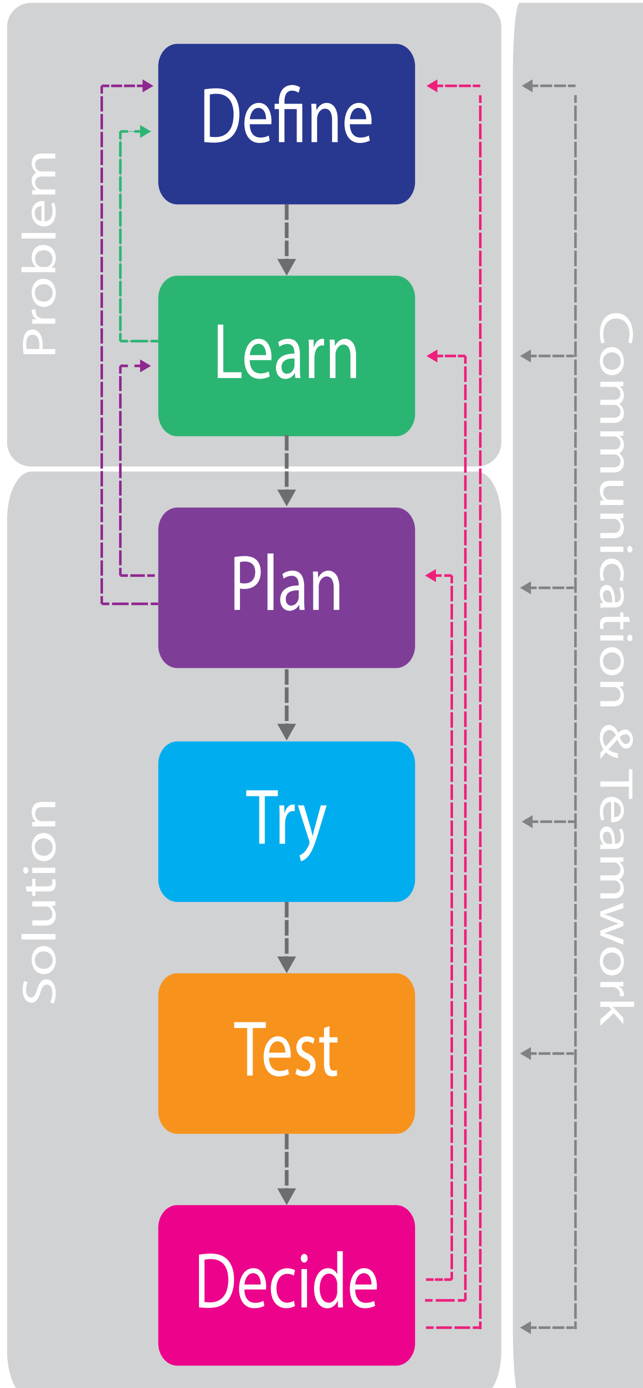


Individual slider

Engineering Design Process
A way to improve



Engineering Design Process
A way to improve



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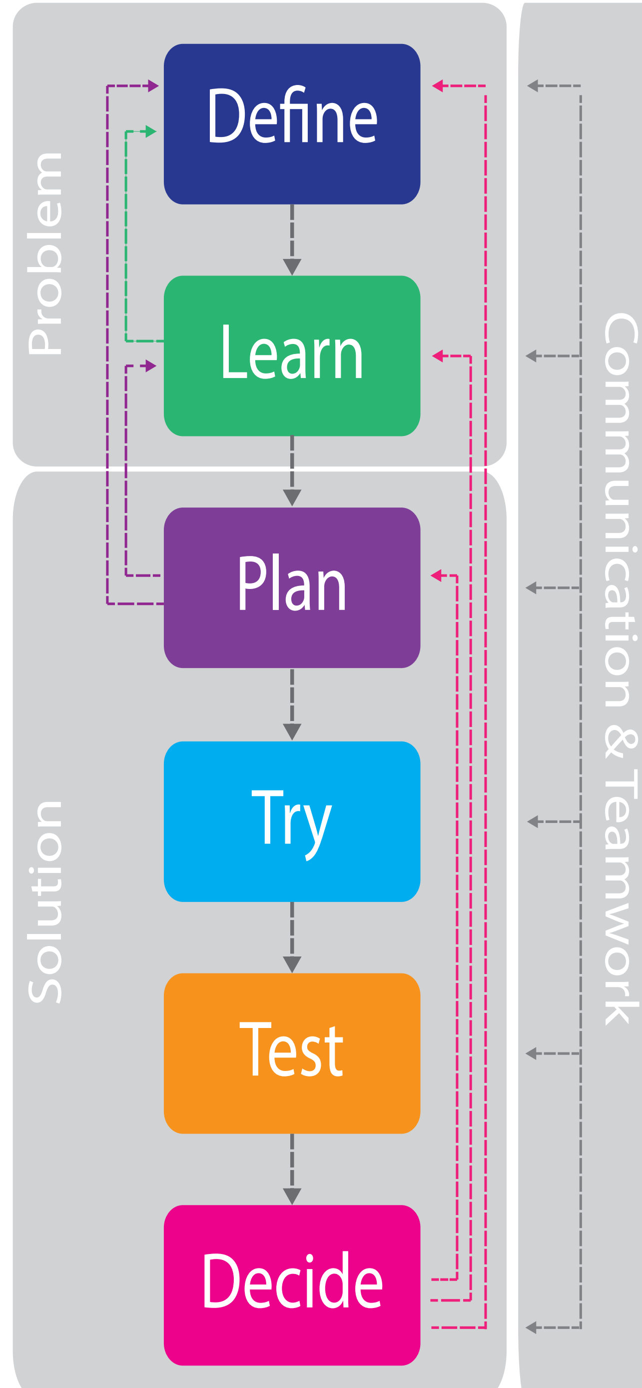
Engineering Design Process
A way to improve



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Overview: Unit Description

Grade Levels:

6-8

Approximate Time Needed to Complete Unit:

Ten to fourteen 50-minute class periods

Unit Summary

Laser Secure, Inc., designs security systems to protect valuable assets, and the company is seeking help from students to design a laser security system to protect the artifacts in a traveling museum exhibit. In this engineering-driven STEM unit, students will investigate properties of light, including reflection, refraction, absorption, and transmission. Based on the data they collect throughout the unit, students will make evidence-based decisions to design, test, and improve prototype security systems.

Science Connections	Technology & Engineering Connections	Mathematics Connections
light, waves, color spectrum, reflection, refraction, absorption, transmission	engineering design process, lasers, computer simulations	angles, measurement

Unit Standards

Next Generation Science Standards

- **MS-PS4-1**: Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave. *Clarification Statement: Emphasis is on describing waves with both qualitative and quantitative thinking*.
- **MS-PS4-2**: Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.
- **MS-ETS1-1**: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- **MS-ETS1-2**: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
- **MS-ETS1-3**: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
- **MS-ETS1-4**: Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Common Core State Standards - Mathematics

- **4.MD.C.5:** Recognize angles as geometric shapes that are formed wherever two rays share a common endpoint, and understand concepts of angle measurement.
- **4.MD.C.6**: Measure angles in whole-number degrees using a protractor. Sketch angles of specified measure.
- **6.SP.A.2:** Understand that a set of data collected to answer a statistical question has a distribution which can be described by its center, spread, and overall shape.

Overview: Unit Description

- **6.SP.B.5:** Summarize numerical data sets in relation to their context, such as by:
  - **6.SP.B.5.A:** Reporting the number of observations.
  - **6.SP.B.5.B:** Describing the nature of the attribute under investigation, including how it was measured and its units of measurement.
- **7.RP.A.2:** Recognize and represent proportional relationships between quantities.
  - **7.RP.A.2.A:** Decide whether two quantities are in a proportional relationship, e.g., by testing for equivalent ratios in a table or graphing on a coordinate plane and observing whether the graph is a straight line through the origin.
  - **7.RP.A.2.B:** Identify the constant of proportionality (unit rate) in tables, graphs, equations, diagrams, and verbal descriptions of proportional relationships.
- **7.G.A.2:** Draw (freehand, with ruler and protractor, and with technology) geometric shapes with given conditions. Focus on constructing triangles from three measures of angles or sides, noticing when the conditions determine a unique triangle, more than one triangle, or no triangle.
- **7.G.A.1:** Solve problems involving scale drawings of geometric figures, including computing actual lengths and areas from a scale drawing and reproducing a scale drawing at a different scale.
- **8.EE.A.4:** Perform operations with numbers expressed in scientific notation, including problems where both decimal and scientific notation are used. Use scientific notation and choose units of appropriate size for measurements of very large or very small quantities (e.g., use millimeters per year for seafloor spreading). Interpret scientific notation that has been generated by technology.
- **8.G.A.1:** Verify experimentally the properties of rotations, reflections, and translations:
  - **8.G.A.1.B:** Angles are taken to angles of the same measure.
- **8.G.A.5:** Use informal arguments to establish facts about the angle sum and exterior angle of triangles, about the angles created when parallel lines are cut by a transversal, and the angle-angle criterion for similarity of triangles.

Unit Assessment Summary

Throughout this unit, students individually maintain an engineering notebook to document their engineering design processes. In this, students make observations, collect data, and plan for their design. Part of the engineering notebook includes answering specific questions related to that day's activities. You may choose to post the questions on your overhead/PowerPoint slides, or give the students printed versions (included as duplication masters in each applicable lesson) to tape into their notebooks. Students use their notebooks as a reference – a place to maintain the information they are learning through design. Additionally, students reflect on their work throughout the design process. This is important for modeling what real-life engineers do. **Collect the engineering notebooks at the end of each class.** You will use the notebooks to assess student learning through their design process. Provide feedback to students on their notebook responses - rubrics are provided. You are encouraged to assign points for responses in the engineering notebooks. **Provide feedback often - especially lessons for which rubrics are provided.**

- The notebook pages are often set up as handouts in each lesson. If you prefer to use notebooks without having students paste copied pages in them, there is an appendix at the end of this unit that includes notebook prompts and how to have students title each entry.
- The final summative piece of this unit requires students to communicate to the client recommending a design and justifying its success as a solution to the engineering problem.

Overview: Lesson Summaries

Lesson 1: Design Challenge Introduction

Students work in small teams to review the Engineering Design Process (EDP). They complete a card-sorting activity to demonstrate their knowledge of the EDP stages and how each stage corresponds to real-world engineering. Students read a client letter that introduces them to the context of their engineering design challenge, a security company that needs a laser security system to protect valuable museum displays.

Lesson 2: Waves and Electromagnetic Spectrum

In this lesson, students explore why the light that shines from a flashlight looks different than the light that comes from a laser pointer. Students learn about the wavelength, amplitude, and frequency of waves and how these relate to the energy of the wave. They discuss the color spectrum and relationships between the wave properties and the color of light seen. Students connect their learning back to the engineering problem of creating a laser security system.

Lesson 3: Light Propagation

Students explore some of the basic properties of light. They observe that light travels in a straight line, spreads out as it moves away from its source, and interacts differently with different surfaces. Students explore absorption and transmission of light using different materials and relate their learning to the engineering design context.

Lesson 4: Intro to Reflection and Refraction

This lesson introduces students to reflection and refraction of light. Through hands-on activities, students observe light as it interacts with mirrors and lenses. They learn that light behaves differently depending on the medium with which it is interacting. Students consider how mirrors and lenses can be of use to them in the engineering design challenge of creating a laser security system.

Lesson 5: Reflection/Refraction Simulation

In this lesson, students read an email from the client with responses to their questions. Students complete a guided exploration of a simulation. By manipulating variables within the simulation, they discover the law of reflection. They also learn that the angle of refraction is dependent upon the medium through which light is passing, which affects the speed of the light. Students connect this learning back to the engineering design challenge, noting how their new content knowledge can help them plan a successful laser security system design.

Lesson 6: Reflection/Refraction Experiments and Data Collection

In this lesson, students apply their learning from the reflection and refraction simulation to a hands-on activity. They conduct controlled experiments to measure angles of reflection and refraction of mirrors and lenses. As they work through a guided lab, students record data they will need for their laser security system prototype design and reflect on how the lab activities will inform their designs.

Overview: Lesson Summaries

Lesson 7: Plan/Build/Test

In this lesson, students apply their previous learning to make a plan for their laser security system. Students individually brainstorm potential design ideas, then work with their teammates to compare ideas and create at least two team plans using precise measurements from their previous labs. To decide between their team plans, students complete evidence-based reasoning graphics to examine their designs in relation to the criteria and constraints of the design challenge. Students make a physical prototype of their laser security system using the design plan they developed in the previous lesson. They test their own security system as well as other teams' designs, then provide feedback to the other teams. Based on their own observations and the feedback they receive from their peers, teams of students identify ways to improve their security system design based on the client's criteria and constraints.

Lesson 8: Redesign

In this lesson, students utilize their reflections from the previous lesson to improve their laser security system prototypes. They work as a team to create a new design plan, then build, test, and evaluate their prototype. Students compose letters to the client to justify why their design fulfills the criteria and constraints. They also reflect on how their understanding of the design challenge has evolved throughout the course of the unit.

Lesson 9: Summative Assessment

In this lesson, students review their learning throughout the unit by revisiting their engineering notebooks and identifying the learning that was most integral to the design challenge. After they have had a chance to talk to their teammates about what they have learned, students complete a summative assessment to demonstrate their learning.

Overview: Unit Overview

Lesson	Time Needed	**Objectives** The student will be able to:
1: Design Challenge Introduction	One 50-minute class period	• identify the steps of the engineering design process. • explain the engineering problem they will be solving.
2: Waves and Electromagnetic Spectrum	One 50-minute class period	• identify the amplitude, frequency, and wavelength of waves. • explain how the wavelength and frequency of light affect the color and energy level of light. • explain why the light emitted by a flashlight appears different from the light emitted by a laser pointer.
3: Light Propagation	One 50-minute class period	• explain that light travels in a straight line and spreads out as it moves away from its source. • explain the difference between absorption and transmission.
4: Intro to Reflection and Refraction	One 50-minute class period	• define reflection and refraction. • identify different types of lenses and how light acts when it passes through them.
5: Reflection/ Refraction Simulation	One-two 50-minute class period	• describe how to use a protractor to measure angles. • explain the law of reflection. • explain that the speed of light depends on the medium through which it is traveling and connect this to the angle of refraction.
6: Reflection/ Refraction Experiments and Data Collection	One 50-minute class period	• use a protractor to measure angles. • explain their observations of reflection and refraction.

Materials	Duplication Masters & Educator Resources
• **Per classroom:** whiteboard or poster paper and markers, optional: computer with projector • **Per student:** 1 red pencil or marker, 1 green pencil or marker, 1 pencil, engineering notebook	**DUPLICATION MASTERS** • 1.a. What Do You Know About Engineers? • 1.b. EDP Card Sort activity • 1.c. Client Letter • 1.d. Problem Scoping **EDUCATOR RESOURCES** • 1.e. Problem Scoping Rubric • 1.f. Problem Scoping Section 2 Answer Key
• **Per classroom:** 1 flashlight, 1 laser pointer, whiteboard or poster paper and markers • **Per team:** 1 long piece of string or 1 helical spring, 1 set of colored pencils (red, orange, yellow, green, blue, indigo, violet) • **Per student:** 1 prism, 1 pencil, engineering notebook	**DUPLICATION MASTERS** • 2.a. Waves and Light
• **Per classroom:** 1 flashlight, 1 mini Mag Light (able to stand up), 3 index cards (any size), binder clips, 1 hole punch, 1 ruler, optional: computer with projector • **Per team:** 1 flashlight, about one square foot each of: aluminum foil, plastic wrap, wax paper, cardboard, paper • **Per student:** 1 colored pencil, 1 pencil, engineering notebook	**DUPLICATION MASTERS** • 3.a. Absorption/Transmission/Reflection Data Table
• **Per team:** 1 flat lens, 1 convex lens, 1 concave lens, 1 plane (flat) mirror, 1 concave mirror, 1 flashlight, 1 laser pointer, 1 ruler • **Per student:** 1 pencil, engineering notebook	**DUPLICATION MASTERS** • 4.a. Mirrors and Lenses Observations
• **Per classroom:** computer with projector • **Per team:** optional: computer or tablet • **Per student:** 1 protractor, 1 red pencil or marker, 1 green pencil or marker, 1 pencil, engineering notebook	**DUPLICATION MASTERS** • 5.b. Protractor Practice • 5.c. Bending Light Simulation **EDUCATOR RESOURCES** • 5.a. Client Email Template
• **Per team:** 1 laser pointer, 1 mirror, 1 convex lens, 1 concave lens, 1 protractor, 1 ruler or straightedge, large binder clips, clay • **Per student:** 1 pencil, engineering notebook	**DUPLICATION MASTERS** • 6.a. Measuring Reflection and Refraction Lab • 6.b. Paper Protractor

Overview: Unit Overview

Lesson	Time Needed	**Objectives** The student will be able to:
7: Plan/Build/Test	Two-three 50-minute class periods	• design a laser security system that incorporates their knowledge of reflection, refraction, absorption, and transmission of light. • engage in evidence-based reasoning to select the design that best addresses the criteria and constraints of the design challenge. • construct a model laser security system that meets the criteria and constraints defined by the client. • provide constructive design feedback to their peers. • identify ways to improve their initial security system designs.
8: Redesign	One-two 50-minute class period	• design a laser security system that incorporates their knowledge of reflection, refraction, absorption, and transmission of light. • use peer feedback and their own observations to improve their design. • construct a model laser security system that meets the criteria and constraints defined by the client. • use evidence to justify whether their design meets the client's criteria and constraints.
9: Summative Assessment	One-two 50-minute class periods	• explain how they utilized the engineering design process within the context of the design challenge. • identify the amplitude and wavelength of waves. • explain why the light emitted by a flashlight appears different from the light emitted by a laser pointer. • explain the difference between absorption and transmission. • apply the law of reflection to predict the angle of reflection when given an angle of incidence. • explain the difference between reflection and refraction.

Overview: Unit Overview

Materials	Duplication Masters & Educator Resources
• **Per classroom:** extra laser pointers • **Per team:** 40 cm x 50 cm grid paper (one sheet per plan), 1 ruler or straightedge, 1 protractor, 1 laser pointer (ideally with a button/switch that keeps it turned on), 1 concave lens, 1 convex lens, 1 flat lens, 3 flat mirrors, 1 concave mirror, 1 model person (attached to pencil), 6-10 large binder clips, baby powder, small brush (such as a makeup brush), petri dish, 7 index cards, clay • **Per student:** 1 pencil, engineering notebook	**DUPLICATION MASTERS** • 7.a. Planning Reflection Questions • 7.c. Evidence-Based Reasoning • 7.h. Test Solution Ideas **EDUCATOR RESOURCES** • 7.b. Planning Reflection Questions Rubric • 7.d. Evidence-Based Reasoning Rubric • 7.e. Evidence Based Reasoning Instructions • 7.f. Teacher Observation Protocol: Try Lesson • 7.g. Teacher Observation Protocol: Test Lesson • 7.i. Test Solution Ideas Notebook Prompt Rubric
• **Per classroom:** extra laser pointers • **Per team:** 40 cm x 50 cm grid paper (one sheet per plan), 1 ruler or straightedge, 1 protractor, 1 laser pointer (ideally with a button/switch that keeps it turned on), 1 concave lens, 1 convex lens, 1 flat lens, 3 flat mirrors, 1 concave mirror, 1 model person (attached to pencil), large binder clips, baby powder, small brush (such as a makeup brush), petri dish, clay • **Per student:** 1 pencil, engineering notebook	**DUPLICATION MASTERS** • 8.a. Redesign Evaluation • 8.e. Unit Reflection **EDUCATOR RESOURCES** • 8.b. Redesign Evaluation Rubric • 8.c. Teacher Observation Protocol: Redesign Lesson • 8.d. Criteria and Constraints Assessment Checklist • 8.f. Unit Reflection Rubric
• **Per student:** 1 protractor, 1 pencil, engineering notebook	**DUPLICATION MASTERS** • 9.a. Unit Review • 9.b. Summative Assessment **EDUCATOR RESOURCES** • 9.c. Summative Assessment Answer Key

Master Material List

	Material	Lessons Where Material is Used
Per classroom	(1) flashlight	2, 3
	(1) laser pointer	2
	(1) mini Mag Light	3
	baby powder	7, 8
	(3) index cards (any size)*	3
	binder clips	3
	(1) hole punch*	3
	(1) ruler*	3
	computer and projector*	1, 3, 5
	whiteboard or poster paper and markers*	1, 2
	hot glue gun and glue sticks	7
	Engineering Design Process (EDP) poster	1, 2, 3, 4, 5, 6, 7, 8, 9
Per team	(3) flat mirrors	4, 6, 7, 8
(assuming 3 students	(1) concave lens	4, 6, 7, 8
per team)	(1) convex lens	4, 6, 7, 8
	(1) flat lens	4, 7, 8
	(1) concave mirror	4, 7, 8
	(1) flashlight	3, 4
	(1) laser pointer	4, 6, 7, 8
	(1) prism	2
	(1) long piece of string or (1) helical spring	2
	(1) set of colored pencils (red, orange, yellow, green, blue, indigo, violet)	2
	(1) piece (approx. one square foot) each of: aluminum foil, plastic wrap, lined paper, wax paper, cardboard, and other miscellaneous materials	3
	40 cm x 50 cm grid paper	7, 8
	large binder clips	6, 7, 8
	small brush (such as a makeup brush)	7, 8
	Petri dish	7, 8
	(1) model person (attached to a pencil)	7, 8
	(7) index cards	7
	clay	6,7,8
	(optional) computer or tablet*	5

Master Material List

	Material	Lessons Where Material is Used
Per student	(1) red pencil or marker	1, 3, 5
	(1) green pencil or marker	1, 3, 5
	(1) ruler*	4, 6, 7, 8
	(1) protractor*	5, 6, 7, 8, 9
	(1) index card*	7
	(1) pencil*	1, 2, 3, 4, 5, 6, 7, 8, 9
	Engineering Design Process (EDP) slider	1, 2, 3, 4, 5, 6, 7, 8, 9
	engineering notebook*	1, 2, 3, 4, 5, 6, 7, 8, 9

*required materials not included in the kit

LESSON 1 Design Challenge Introduction

Lesson Objectives
Students will be able to:
- identify the steps of the engineering design process.
- explain the engineering problem they will be solving.

Time Required
One 50-minute class period

Materials
Per classroom:
- whiteboard or poster paper and markers
- **(optional)** computer with projector
- Engineering Design Process poster

Per student:
- (1) red pencil or marker
- (1) green pencil or marker
- (1) pencil
- engineering notebook
- Engineering Design Process slider

Standards Addressed
Next Generation Science Standards: MS-ETS1-1

Key Terms
constraints, criteria, client, end user, engineering design process

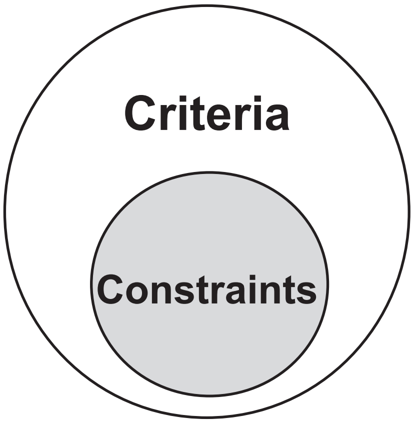
Lesson Summary
Students work in small teams to review the Engineering Design Process (EDP). They complete a card sort activity to demonstrate their knowledge of the EDP stages and how each stage corresponds to real-world engineering. Students read a client letter that introduces them to the context of their engineering design challenge, a security company that needs a laser security system to protect valuable museum displays.

Background
Teacher Background
Teamwork: Students should be teamed strategically and may or may not be assigned roles within their team. When forming student teams, consider academic, language, and social needs. In place of strategic teaming, a random teaming can be substituted. Students will work in these teams, or "teams," of three or four throughout the unit. Effective teamwork is essential in this unit as well as in engineering in general; however, this unit does not provide specific support to develop those skills. If students do not have experience with teamwork, targeted team-building activities are highly recommended prior to beginning this unit.

Engineering Design Process: Students should have some familiarity with the engineering design process before beginning the unit. If they do not, the teacher will need to spend additional time explaining it, so this lesson may take more than one day. The engineering design process (EDP) is an iterative, systematic process used to guide the development of solutions to engineering problems. There is no single engineering design process, just like there is not one scientific method. However, the various engineering design processes have similar components. The engineering design process (EDP) is an iterative process that involves understanding the problem, learning background information necessary to solve the problem, planning, trying, testing the solution, making changes based on the tests, and communicating their ideas. Students will use a engineering design process slider throughout the unit to help them understand where they are in the design process. For more information about the steps of the engineering design process presented in this unit, see the front matter section about it.

Some common misconceptions about the EDP:
- Engineers do not have to learn anything new when they are working on a project.
  - **In reality:** Engineers need to continually learn throughout their lives.
- The engineering design process is linear, and you never need to go back to previous phases.
  - **In reality:** The EDP is a cyclical process that requires many iterations.
- Once engineers are done with a project, they never think about it again.
  - **In reality:** A project is never really "done," and engineers often continue to improve and make changes.

Criteria and constraints: One difficulty students might have is distinguishing between criteria and constraints. Criteria are the things required for a successful design, or goals of the designed solutions. They help engineers decide whether the solution has solved the problem. Another way of thinking about criteria are that they are anything that the client and the engineers will use to judge the quality of a solution. Constraints are a specific type of criteria; they are those criteria that limit design possibilities, or the ways that the problem can be solved. If constraints are not met, the design solution is by default not a viable solution to the problem. The relationship between criteria and constraints is represented in the figure. It may be helpful to post the definitions with the figure somewhere in the classroom for future reference.



Cost is a common example of something that can be a criterion and a constraint. If the client requires engineers to stay within a specific budget, then this budget is a constraint. Any design solution that requires more money than the budget is automatically disqualified from being a quality solution. However, cost is also a relative criterion. Multiple design solutions that stay within the budget can be proposed. The costs of these solutions could be compared as one factor to determine which of the solutions is preferable.

Problem Scoping: In this lesson, students will be in the Problem Scoping section of the engineering design process, specifically on the define the problem step. Define the problem and learn about the problem combine to make Problem Scoping. In this stage, students will be first introduced to the engineering problem through a client letter and then be given a chance to ask questions to the client to receive more information about the problem. The problem statements given in the client memos purposefully do not provide all the information necessary to solve the problem. Students are tasked with generating questions about the problem to try to fill in this missing information. Based on all information from the client, students will then define the problem in terms of: what the problem is and why it is important, who are the client and end users, what are the criteria and constraints, and what other information they may need to learn about in order to solve the problem. This process of generating ideas and questions for the client is an important skill on its own both in engineering and in other fields, but it also helps to ensure that the students fully understand the problem and their task in the engineering design challenge.

Solution Generation: The Solution Generation section of the engineering design process includes plan the solution, try out the plan of the solution, test the solution, and decide whether the solution is good enough. When engineers are generating solutions, they will use iteration as a means to continually improve their solution, reflect back on the problem definition and what they have learned about the problem, and consider criteria, constraints, and trade-offs. Trade-offs involve having to make compromises about which criteria to emphasize because they compete with one another in terms of making the solution effective. For example, cost could be a trade-off for

Assessments

Pre-Activity Assessment
Read students responses to the prompts: *What do engineers do?* and *How do engineers solve problems?*

Activity Embedded Assessment
Observe how students complete the EDP sorting activity, noting any misconceptions students may have.

Post-Activity Assessment
Read student responses to the problem-scoping prompts. Use the *1.e. Problem Scoping Rubric* to provide feedback to the students.

DUPLICATION MASTERS

- 1.a. What Do You Know About Engineers?
- 1.b. EDP Card Sort
- 1.c. Client Letter
- 1.d. Problem Scoping

EDUCATOR RESOURCES

- 1.e. Problem Scoping Rubric
- 1.f. Problem Scoping Section 2 Answer Key

durability.

Engineering notebook: Throughout the unit students will be recording information in an engineering notebook, and they will need the notebook immediately in Lesson 1. Students' engineering notebooks will support their communication of ideas and should be used consistently throughout the unit. A number of worksheets are provided as duplication masters. If these worksheets are printed for students, they should be taped or stapled into their engineering notebooks so all of the unit information is stored within the notebooks.

Vocabulary: Students will be introduced to many new science and engineering vocabulary terms throughout the unit. It may be helpful to create a vocabulary section in their notebook with term definition and memory clue or picture. Additionally, the class could maintain a word wall.

Before the Activity

- Choose which video clip to show at the beginning of class to introduce laser security systems. A possible video clip is avaliable at http://funovation.com, or find the Funovation channel on YouTube. Show any age-appropriate movie clip that contains a laser security system (e.g. Ocean's Twelve, Get Smart, etc.).
- Post the Engineering Design Process poster in the classroom and create the EDP sliders (see hte front matter for how to assemble them).
- Determine student teams (ideally teams of three). These teams should be their teams throughout the rest of the unit.
- Make copies of the duplication masters:
    - *1.a. What Do You Know About Engineers?* (1 per student)
    - *1.b. EDP Card Sort* (1 per team)
    - *1.c. Client Letter* (1 per student)
    - *1.d. Problem Scoping* (1 per student)

  NOTE: See pages 124-126 for instruction for using notebooks rather than duplication masters.
- Cut up the EDP cards. NOTE: If you are using notebooks, it is still recommended to print the *1.b. EDP Card Sort* and *1.c. Client Letter.*

Classroom Instruction

Introduction

1. **Set up engineering notebooks.** Direct students to take out their engineering notebooks. Explain to the students that they will be using their notebook to record their ideas for the engineering challenge. Guide them through making a table of contents on the first page.

2. **Complete problem scoping section 1.** Distribute *1.a. What Do You Know About Engineers?* **Say:** *In this unit, we are going to be working on an engineering challenge. Before we get started, you're going to respond to some prompts about engineers and what they do.* Direct students to respond to the prompts.

3. **Form teams.** After students have finished responding to the prompts, explain that they will start the day with a review of the engineering design

process, then look at a specific problem that will require the use of that process. Explain that students will be working in small teams to solve a problem being brought to them by the client. Divide students into teams of three.

Activity

4. **Introduce the engineering design process.** As a whole class, review the engineering design process and introduce the EDP slider. This can be carried out in different ways depending on students' knowledge of EDP and the needs of the students. Students could volunteer their ideas about the steps of the engineering design process and the teacher could guide the discussion, or the teacher could lead the discussion to explain the stages of the EDP. This is an example of a different engineering design challenge that others have solved using the engineering design process.

5. **Complete engineering design process card sort. Say:** *I will be giving you cards that describe different steps someone took to solve an engineering challenge. Your task is to match each step with the correct phase of the engineering design process. This will help you understand the steps that we'll be taking throughout our new challenge.* Distribute cards to student teams and display the following directions on the board: *Sort your cards into six different sets so that each phase of the engineering design process is represented. Each set will have the single-word name of the EDP phase, a description of what happens in that phase, and a real-world example of what engineers might do in that phase.* As students are working, look for any misconceptions about the EDP, including those listed in the teacher background. There are two options to conclude this activity:
   - Ask for student volunteers to share their solutions.
   - Have two teams join each other and discuss similarities and differences in how they sorted their cards.

6. **Introduce the video on laser security systems. Say:** *Now that we know more about the engineering design process, we're going to see how the process can be used to solve a real-world problem. I am going to play a short video, and while you are watching it, think about the questions: What problem did the person have to solve? What knowledge did they need to solve the problem?* Play the video for students, then give them time to discuss their answers to the questions with their teams. Direct students to look back at their responses to *1.a. What Do You Know About Engineers?*. Explain that they are going to work with their teammates to add more detail to describe what engineers do and how they solve problems. **Say:** *With your teams, work together to add more detail to your responses. Make sure to record your team responses in a different color than you used for your individual responses.*

7. **Identify where they are in the engineering design process. (Define)** **Say:** *Engineers need to first define the problem in detail before they can learn more about the problem and design a solution. This is what we will be doing today.*

Design Challenge Introduction

8. **Introduce the engineering challenge through the client letter. Say:** *Since we've seen how the engineering design process can be used to solve problems, we will be looking at the engineering challenge that we will be working on for the rest of this unit.* Explain to students that they will be getting a letter from a client that needs their help. They will need to read the *1.c. Client Letter* to learn more about the problem they will be solving and identify what additional information they will need. Any criteria, or things that are required for a successful design, should be underlined in green. Constraints, or limits on how students can solve the problem, should be underlined in red. The client letter can be introduced and processed in several different ways:
   - Students individually read and annotate the letter.
   - Students read the letter in their teams and discuss the important aspects.
   - Read and annotate the letter as a whole team.

9. **Complete problem scoping section 2.** Distribute *1.d. Problem Scoping* worksheets. After reading the letter, direct students to respond to the Problem Scoping - Section 1 prompt on their *1.d. Problem Scoping* worksheets. They can do this individually or in teams. Explain that students should record any questions they have for the client at this point. The questions can serve to clarify or provide more information about what was mentioned in the letter, or they could be related to something that wasn't addressed at all by the client, like the science they'll need to use to create a laser security system. After students have had time to develop questions and discuss with their teams, have teams take turns sharing questions. Record a class list of questions on the whiteboard or poster paper. Continue sharing questions until all questions are listed on the class list. Possible questions include:
   - What materials can we use?
   - How much time do we get?
   - How big is the room with the artifacts?
   - What cities will the traveling exhibit visit?
   - What artifacts need to be secured?
   - How big are the artifacts that need to be protected?

   Remind students that they should continue to think about questions to ask the client throughout the design challenge.

10. **Complete problem scoping section 2.** Direct students to the *1.d. Problem Scoping* worksheet - section 2. **Say:** *You are going to fill out this section of the worksheet using the information you have acquired from the client letter at this point. First, you'll fill in your individual responses to each prompt, then you'll work with your team to add your team responses. Remember that the client is the company who contacted us to do this work. The end users are the people who will actually end up using the product you design.* Remind the students that they will continue to learn more about the challenge throughout the unit. Students should first respond to the prompts individually and then discuss their answers with their teams. If time is short, the team discussions can be done at the beginning of Lesson 2.

Closure

11. Review problem scoping. If time allows, discuss the problem scoping prompts with the whole class. If time is short, one or two of the more difficult prompts could be discussed, or each team could share their response to a question. **Ask:** *In relation to our design challenge, which phase of the engineering design process did we focus on today? How do you know?*

LESSON 1

Name________________________ Date____________ Period _____

1.a. What Do You Know About Engineers?

Directions: Please answer the following questions.

1. What do engineers do?

2. How do engineers solve problems?

LESSON 1

Name________________________ Date____________ Period _____

1.a. What Do You Know About Engineers?

Directions: Please answer the following questions.

1. What do engineers do?

2. How do engineers solve problems?

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LESSON 1

Name______________________________ Date__________ Period _____

1.b. EDP Card Sort

Define	Determine who the client is and what the client needs. Identify criteria and constraints.	Vaccines help prevent the spread of disease, but they need to be kept cool without freezing. This can be challenging in parts of the world with warm climates and unreliable electricity. The True Chill Company needs engineers to design a cooler that does not use electricity and can keep a vaccine between 32 and 42 degrees Fahrenheit for at least 10 minutes under a heat lamp.
Learn	Identify background science and math knowledge that will be needed to solve the problem. Determine what has already been done and how you will measure success.	Research heat energy and how it moves. Learn more about how different materials affect the movement of heat. Learn about how heat can be measured.
Plan	Develop multiple ideas to solve the problem. Consider trade-offs of each possibility and develop a plan.	Review what has been learned about the engineering problem and the science and math concepts that need to be applied to solve the problem. Generate multiple possible cooler designs and decide which design would be most likely to keep a vaccine cool. Determine how the design will be constructed.
Try	Put your plan into action, building a prototype model, process, or product.	Create a prototype of the cooler based on the engineering team's plans.
Test	Conduct a test of your design or solution to determine whether it is meeting the needs, criteria, and constraints. Collect and analyze data from your prototype.	Test the cooler prototype's performance. Determine whether it is able to keep a vaccine between 32 and 42 degrees Fahrenheit for at least 10 minutes while under a heat lamp. Collect data as the prototype is tested.
Decide	Determine whether your solution is good enough to meet the needs of the client while staying within the constraints. Identify ways your design could be improved.	Evaluate whether the solution meets the needs of The True Chill Company. Determine whether there are parts of your cooler that should be redesigned.

LESSON 1

Name________________________________ Date___________ Period _____

1.c. Client Letter

Laser Secure, Inc.
2233 Cherry Blossom Drive
Washington, DC 20002

LASER SECURE

Dear Engineers,

Our company provides security systems to homes and businesses around the world. We work to make sure that people and property remain safe and protected from harm or theft. Despite our best efforts, one of our clients was recently robbed, and we write to you in the hopes that you can help design a security system that will protect against future theft.

The security system you design will be used by traveling museum exhibits that bring valuable displays to museums around the country. Some display items might include fossils, jewelry, art, sports memorabilia, and other items to be viewed by the public. The artifacts that will be displayed are priceless, so we need your help to design a security system to protect them.

You will need to draw on your scientific knowledge to create a laser security system using light from a single laser. Each host city might choose a different layout for the artifacts, and the security system will be for the entrance room to the museum that contains the key artifacts from the collection. You will need to decide with your team how many artifacts to display in the entrance room and where to place the artifacts in relation to your security system. Your design must ensure that a thief will need to cross the laser light at least three times from where they enter the room to where they reach the artifacts. The laser security system must be complicated enough to deter thieves from attempting to steal the artifacts. Therefore, the laser light must refract at least one time and reflect at least one time.

You will work on this design challenge in teams of three or four engineers. We have a limited budget, so you will have limited materials to use in your designs. Our company will review each team's design to determine which would serve as strong security systems. We would like to have the security system in place as soon as possible, so we appreciate your prompt work.

Thank you for helping us solve this problem.

Sincerely,

Lou A. S. E. Richards

Lou A. S. E. Richards

LESSON 1

Name____________________________________ Date___________ Period _____

1.d. Problem Scoping (1/2)

Section 1

Directions: Please answer this question after hearing about the engineering challenge.

1. What are at least 3 questions that you want to ask the client that will help you understand the problem better? Make sure to ask about all important aspects of the problem.

Section 2

Directions: Please answer the following questions after you have been able to ask questions about the challenge.

First, **on your own**, answer each of the following questions beside the "My Response" space. Then, **in your teams**, each person is to share their response and discuss. In the "Team Response" space, write your revised answer to the question, based on discussion with your team. You may use a different color writing utensil to distinguish your answer and how it changed after talking with teammates.

2. Who is the client?

   My response:

   Team response:

3. What is the client's problem that needs a solution? Explain why this is important to solve. Use information from your client to support your reasons.

   My response:

   Team response:

LESSON 1

Name____________________________________ Date___________ Period _____

1.d. Problem Scoping (2/2)

4. Who are the end-users?

   My response:

   Team response:

5. What will make your solution effective (criteria)? Use detailed information you have from the client.

   My response:

   Team response:

6. What will limit how you can solve the problem (constraints)? Use detailed information you have from the client.

   My response:

   Team response:

7. Think about the problem of protecting valuable artifacts. In terms of securing the traveling museum exhibit artifacts, what are at least 2 things you need to learn in order to design a successful laser security system?

   My response:

   Team response:

LESSON 1

Student Name________________________ Date____________ Period _____

1.e. Problem Scoping Rubric

Problem	Question	Learning Objectives	Rubric	
1.d.1	What are at least 3 questions that you want to ask the client? Ask questions that will help you understand the problem better. Make sure to ask about all important aspects of the problem.	Ask a variety of relevant questions to better understand problem.	**Asked at least 3 questions** CIRCLE: 0 1 2 3 4+	
			At least 3 questions are relevant to the problem CIRCLE: 0 1 2 3 4+	
			Considered at least 2 different aspects of the problem CIRCLE: 0 1 2 3 +	
1.d.2	Who is the client?	Identify the client.	yes no	**Correctly identified the client**
1.d.3	What is the client's problem that needs a solution? Explain why this is important to solve. Use information from your client to support your reasons.	Explain the problem based on a synthesis of information.	yes no	**Identified problem**
		Explain why the problem is important to solve based on evidence that is relevant to the problem.	yes no	**Explained why the problem is important**
			yes no	**Provided rationale from client information**
1.d.4	Who are the end-users?	Identify a specific and relevant end user.	yes no	**Correctly identified at least 1 end user**
1.d.5	What will make your solution effective (criteria)? Use detailed information you have from the client.	Explain criteria based on given information.	yes no	**Identified at least 1 criterion**
			yes no	**Connected information from client to criteria**

LESSON 1

Student Name________________________ Date__________ Period _____

1.e. Problem Scoping Rubric

Problem	Question	Learning Objectives	Rubric	
1.d.6	What will limit how you can solve the problem (constraints)? Use detailed information you have from the client.	Explain constraints based on information.	yes no	**Identified at least 1 constraint**
			yes no	**Connected information from client to constraints**
1.d.7	Think about the problem of protecting valuable artifacts. In terms of securing the traveling museum exhibit artifacts, what are at least 2 things you need to learn in order to design a successful laser security system?	Explain the background knowledge needed to develop a solution.	**Identified at least 2 topics they needed to learn** CIRCLE: 0 1 2 3 +	
			Topics are relevant to the problem CIRCLE: 0 1 2 3 +	
			Considered at least 2 different aspects of the problem CIRCLE: 0 1 2 3 +	

Notes:

1.f. Problem Scoping – Section 2 Answer Key

Section 2

1. **Who is the client?**

   Lou A. S. E. Richards who works for Laser Secure.

2. **What is the client's problem that needs a solution? Explain why this is important to solve. Use information from your client to support your reasons.**

   A traveling museum display has valuable artifacts that need to be protected from potential thieves. The artifacts need to be protected so that everyone can see them and the museum does not lose valuable artifacts.

3. **Who are the end-users?**

   The people who set up the traveling museum.

4. **What will make the solution effective (criteria)?**

   (Main) A potential thief will have to cross the laser beam at least three times between the door and any artifacts in the room. The light will reflect at least once and refract at least once. (Possible Additions) The artifacts need to be displayed well for people coming to the museum.

5. **What will limit how you can solve the problem (constraints)?**

   Constraints: There is one laser light source to use. There are limited materials and time available (specific amounts are unknown at this point). The room has certain dimensions, which are also unknown at this point.

6. **Think about the problem of protecting valuable artifacts. In terms of securing the traveling museum exhibit artifacts, what are at least 2 things you need to learn in order to design a successful laser security system?**

   Answers will vary. Potential ideas include: how light travels, reflection, refraction, etc.

LESSON 2

Waves and Electromagnetic Spectrum

Lesson Objectives

Students will be able to:

- identify the amplitude, frequency, and wavelength of waves.
- explain how the wavelength and frequency of light affect the color and energy level of light.
- explain why the light emitted by a flashlight appears different from the light emitted by a laser pointer.

Time Required

One 50-minute class period

Materials

Per classroom:

- (1) flashlight
- (1) laser pointer
- whiteboard or poster paper and markers
- Engineering Design Process poster

Per team:

- (1) long piece of string or (1) helical spring
- (1) set of colored pencils (red, orange, yellow, green, blue, indigo, violet)
- (1) prism

Per student:

- (1) pencil
- engineering notebook
- Engineering Design Process slider

Standards Addressed

- Next Generation Science Standards: MS-PS4-1, MS-ETS1-1
- Common Core State Standards – Mathematics: 4.G.A.3, 8.EE.A.4

Key Terms

wave, amplitude, wavelength, frequency, color spectrum

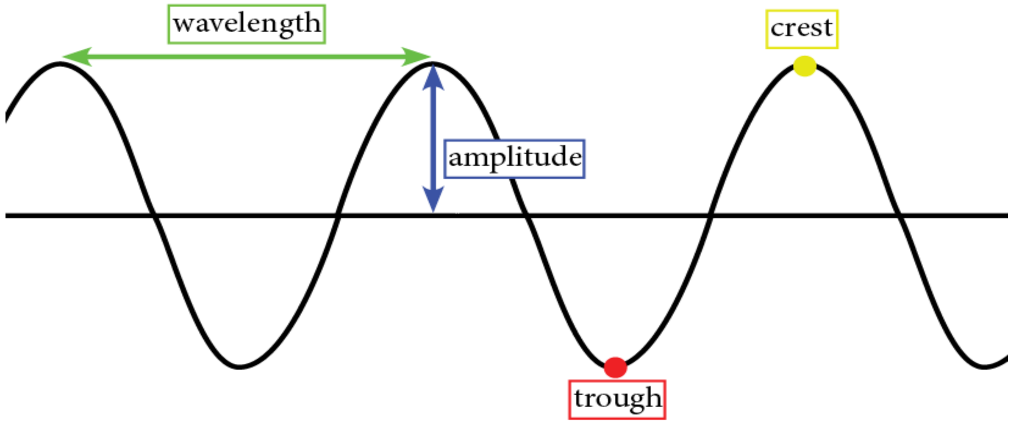
Lesson Summary

In this lesson, students explore why the light that shines from a flashlight looks different than the light that comes from a laser pointer. Students learn about the wavelength, amplitude, and frequency of waves and how these relate to the energy of the wave. They discuss the color spectrum and relationships between the wave properties and the color of light seen. Students connect their learning back to the engineering problem of creating a laser security system.

Background

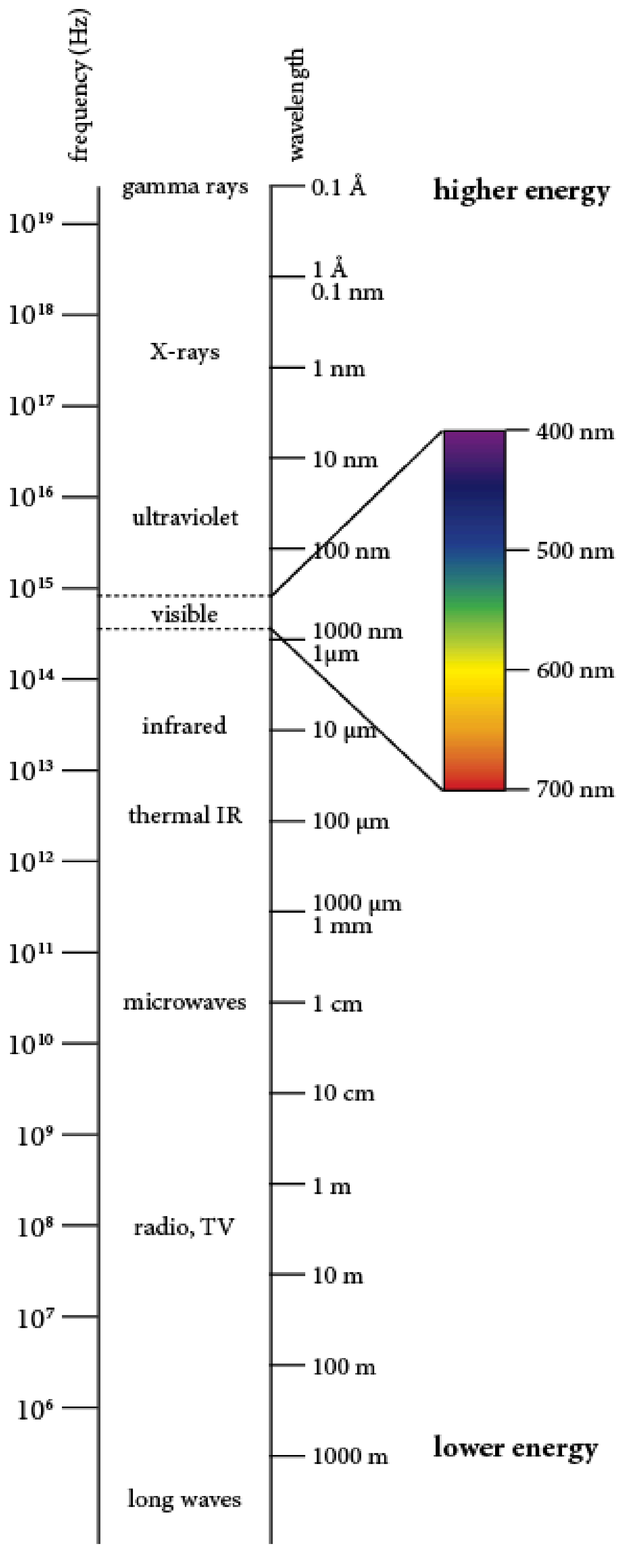
Teacher Background

As written, this lesson assumes that students do not have prior instruction in waves. If the class has already learned waves earlier in the course, this lesson can be adapted to only include the later parts of the lesson that relate waves and light properties. This lesson introduces the properties of waves and touches on the concept that light has properties of a wave. The main emphasis is on the parts of a wave (amplitude, wavelength, frequency) and what happens to the wave when these are changed. Waves transfer energy, not matter. Examples of waves include water waves, sound waves, and light waves. The amplitude (distance, measured in meters, etc.) is the distance from the midline of the wave to the top of a crest or from the midpoint of the wave to the bottom of a trough. The wavelength (distance, measured in meters, nanometers, etc.) is the distance from a trough to a trough, a crest to a crest, or from any particular point on the wave until the next identical point. The frequency (measured in hertz, one hertz is once per second) is how often the wave passes a point.



The main purpose of this information for this unit is for students to understand that waves with high frequencies (shorter wavelengths) have higher energy. In the visible spectrum, red light has the lowest energy level and violet light has the highest energy. The other colors are distributed in between in rainbow order.

Visible light is only a small portion of the wavelengths of light that actually exist. Past red light is infrared light and past violet light is ultraviolet light. Light with high energy (ultraviolet, X-rays, etc.) is harmful to people, light with low energy (infrared, microwaves, radio waves, etc.) is not harmful because high energy waves can cause human cells to mutate. There are many videos available online that can be used to supplement the information you provide students. Possible video options include Bill Nye, BrainPOP, and BirdBrain Science.



Assessments

Pre-Activity Assessment
Check student understanding of the engineering context and challenge through their responses to the question, *What do you remember about the client's problem, criteria for effective solutions, and constraints?*

Activity Embedded Assessment
Examine students' diagrams of waves and the color spectrum in their engineering notebooks. Look for distinctions between amplitude, wavelength, and frequency in the wave diagrams and connections between color, frequency, and energy in the color spectrum.

Post-Activity Assessment
Check student understanding based on their responses on the Waves and Light worksheet.

DUPLICATION MASTERS

- 2.a. Waves and Light

DUPLICATION MASTERS

- 2.a. Waves and Light Answer Key

LESSON 2

Waves and Electromagnetic Spectrum

Before the Activity

- Test helical spring or piece of string to ensure that waves will be visible to students. Cut string to an appropriate length for the class demonstration or small team exploration.
- Make copies of the duplication master (1 per student).

Classroom Instruction

Introduction

1. **Review the engineering design challenge.** Remind students of the client letter introduced yesterday. **Ask:** *What do you remember about the client's problem, criteria for effective solutions, and constraints?* If students were unable to finish their team responses to Problem Scoping - Section 2, allow time for teams to discuss their individual responses and add their team responses. **Ask:** *What kind of scientific knowledge do you think you will need to design a laser security system as the client described?* Guide students to realize that they will need to learn about light for the engineering challenge.

2. **Identify where they are in the engineering design process. (Learn)** **Ask:** *What phase of the engineering design process do you think we will be using today? Why?* Refer students to their EDP sliders.

Activity

Waves

3. **Introduce waves. Say:** *Today, we're going to start learning about light so that we have the science content knowledge we need to apply to our engineering designs.* Shine a flashlight with white light and a colored laser pointer next to each other. **Ask:** *What difference do you see between the flashlight and the laser pointer?* and write the question on the board: *What is the difference between white light and laser light?* Students will likely observe that the light from the flashlight is white or yellowish and the light from the laser is a specific color and that the laser light is more directed than the flashlight light. **Say:** *Today, we're going to learn more about light so we can start to understand the difference between white light and laser light. Light has some properties of waves, so the first thing we need to do is learn about waves.*

4. **(Option 1) Complete wave demo.** Have a student volunteer hold one end of the long string. Explain to students that light travels like a wave and the demo uses a string so that they can see what is going on. Start a wave on the string by moving the end of the string up and down. **Ask:** *What do you observe?* Emphasize that the wave has a certain height and has low points and high points. **Ask:** *What will happen if I move the string up and down faster, putting more energy into the wave?* Accept student predictions, then increase the speed. **Say:** *When I move the string more and put **more energy** into the wave, the **frequency increases**, so the wave comes more often. The **wavelength decreases.*** Draw a wave on the board and explain the different parts of the wave (wavelength, amplitude, and frequency) and how they relate to the wave demo. Have students record the wave and label the different parts in their notebooks. If necessary, show the demonstration

again so that students can understand the relationship between increasing energy and increasing frequency and the inverse relationship between frequency and wavelength.

5. **(Option 2) Complete small team exploration.** Introduce the vocabulary first by drawing a wave on the board and explaining the different parts of the wave (wavelength, amplitude, and frequency). Have students record the wave and label the different parts in their notebooks. Direct students to work in teams with a piece of string to explore the question: *What will happen if I move the string faster up and down and put more energy in the wave?* Have them record observations about how an increase in energy change the wave. Ask a couple of teams to present their work to the class. As a team, discuss the relationship between energy, frequency and wavelength.

6. **(Optional) Complete other demonstrations.** Introduce other wave demos and simulations as needed for students' understanding, such as PhET Wave On a String or Glencoe Virtual Lab Waves.

7. **Review wave vocabulary.** After completing option 1 or option 2, direct the students to draw two waves in their engineering notebooks. One of the waves should have a higher frequency than the wave they drew when they first labeled the parts. The other wave should have a lower frequency than the wave they initially drew. Direct students to indicate which wave has the highest energy, which has the lowest energy, which has the longest wavelength, and which has the shortest wavelength.

Color Spectrum

8. **Introduce the color spectrum. Say:** *Now we're going to return to the question: Why does light have different colors? Each color is different because it has a unique wavelength. Wavelengths get longer in a certain order. You might have seen this certain order before in a rainbow.* Ask for a student volunteer to draw the rainbow order for the whole class to see with red on the bottom. Reinforce the names of each color: red, orange, yellow, green, blue, indigo and violet. A potential memory cue is ROY G. BIV. **Say:** *The scientific word for the rainbow order of colors is the "color spectrum." In the color spectrum, red light has the longest wavelength of about 650 nanometers.* Explain that 650 nanometers is 0.000000065 meters and that this number can be expressed as 6.5×10^{-9} m, which scientists and engineers call "scientific notation." **Say:** *Violet light has the shortest wavelength, about 400 nanometers.* On the color spectrum on the board, label red and violet to show which has the longest and shortest wavelength. Direct students to copy the color spectrum with these labels in their engineering notebooks.

9. **Discuss the color spectrum. Say:** *In your teams, I'd like you to think about two questions:*
   - If red light has the longest wavelength and violet light has the shortest wavelength, which one has a higher frequency?
   - Which color has the highest energy?

Discuss the answers as a class to reach the conclusion that red has the lowest frequency and lowest energy. Add these labels on the color spectrum and have students also record in their notebooks.

10. **Discuss the difference between a laser and a flashlight. Say:** *Let's look back at the question from the beginning of class: How is a laser different from a flashlight with white light?* Distribute prisms to student teams and direct students to look through the prisms to see the color spectrum. This will work the best if they look through the length of the prism at a classroom overhead light or other white light. **Say:** *White light is all of the other colors mixed together. When you look through the prism, it breaks the light into the different colors that come together in white light. The main difference between lasers and white light is that lasers only have one wavelength of light, while white light has many different wavelengths mixed together. Because lasers only have one wavelength, they can be very precise.* Point out on the laser pointer that it says what the wavelength is and that different color lasers will have different wavelengths recorded.

11. **Discuss infrared and ultraviolet light.** Briefly explain to students that there are other wavelengths of light that our eyes aren't able to see, such as ultraviolet and infrared light. To help students understand the different energy levels, explain that ultraviolet (UV) light causes sunburn and skin cancer because it has high energy. Since it is close to violet on the electromagnetic spectrum, violet also has high energy. Infrared is not harmful, and it is often used for night vision goggles. Infrared is close in energy to red light, which is also low energy. Label these on the color spectrum and have students record in their notebooks. This step could be done after the Waves and Light worksheet if students are able to learn more in depth about the color spectrum.

12. **Complete the Waves and Light worksheet.** Direct students to complete the *2.a. Waves and Light* worksheet in their teams. After students have had time to fill out their worksheets, discuss the solutions as a whole class.

Closure

13. **Review science knowledge.** Remind students that this science knowledge will be necessary to solve the engineering design challenge. Direct students to respond to the following questions in their engineering notebooks:
    - How will the science I learned today help me solve the problem of the laser security system?
    - What do I still need to learn to solve the problem of the laser security system?

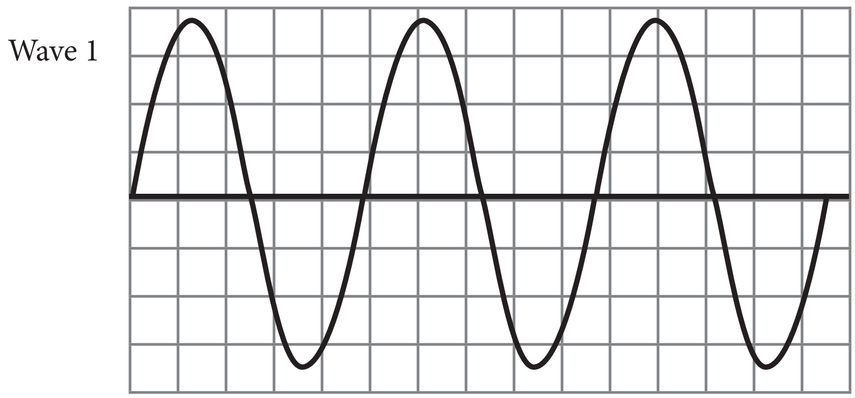
Waves and Electromagnetic Spectrum

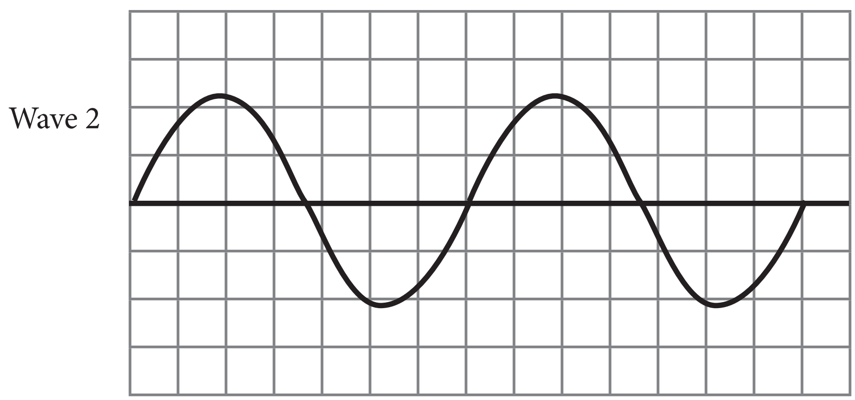
LESSON 2

Name________________________________ Date___________ Period _____

2.a. Waves and Light

1. Answer the following questions about the waves shown below.





b. Label the amplitude and wavelength for each wave.

c. Which wave has a greater amplitude?

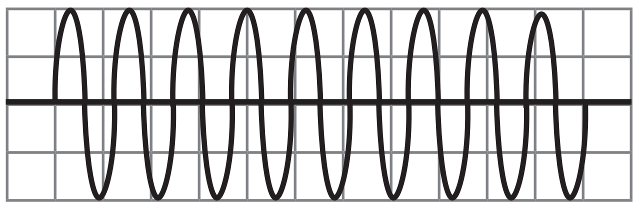
d. Which wave has a longer wavelength?

Name________________________________ Date____________ Period ______

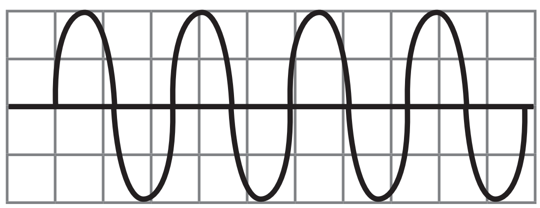
2.a. Waves and Light

2. Answer the following questions about the waves shown below.

Wave 3



Wave 4



a. Label the amplitude and wavelength for each wave.

b. Which wave has a longer wavelength?

c. Which wave has a higher frequency? How do you know?

d. Which wave transfers more energy? How do you know?

Name__________________________________ Date____________ Period _____

2.a. Waves and Light (3/3)

3. Fill in the table below with information about the color spectrum.

Color (Use colored pencils)	**Energy Levels** (Label the lowest and highest, then draw an arrow from low to high.)	**Frequency** (Label the lowest and highest, then draw an arrow from low to high.)	**Wavelength** (Label the shortest and longest, then draw an arrow from low to high.)
Ultraviolet			
Infrared			

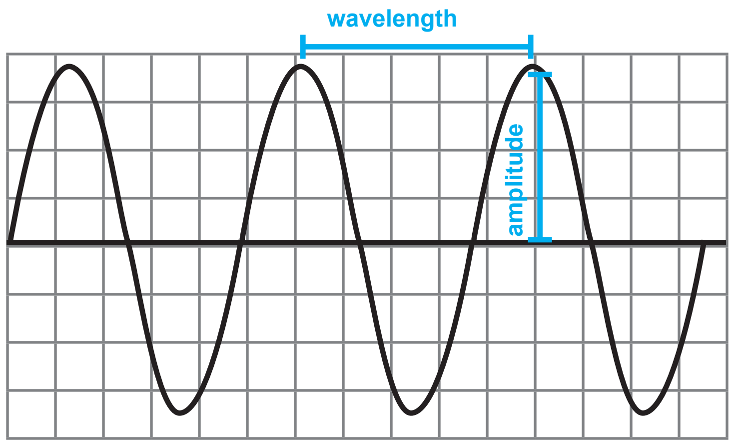
4. What is at least one reason the light from a colored laser is different from the light from a flashlight with white light?

Name________________________________ Date___________ Period _____

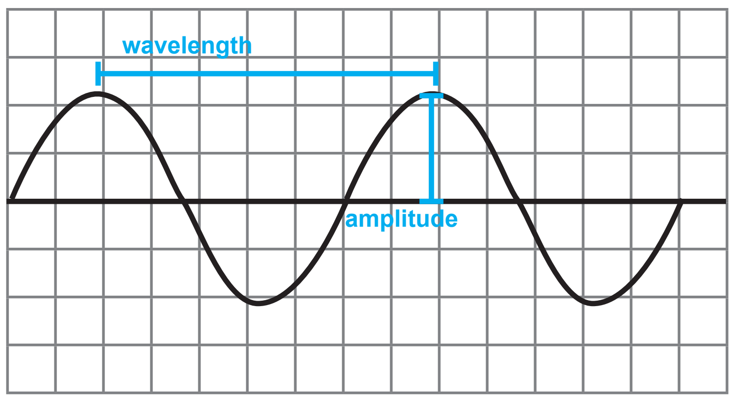
2.a. Waves and Light Answer Key (1/3)

1. Answer the following questions about the waves shown below.

Wave 1



Wave 2



b. Label the amplitude and wavelength for each wave.

c. Which wave has a greater amplitude?

Wave 1

d. Which wave has a longer wavelength?

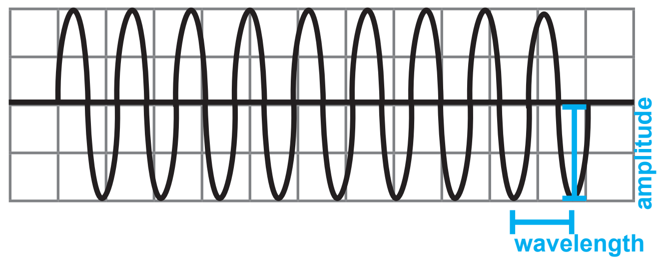
Wave 2

Name________________________________ Date___________ Period _____

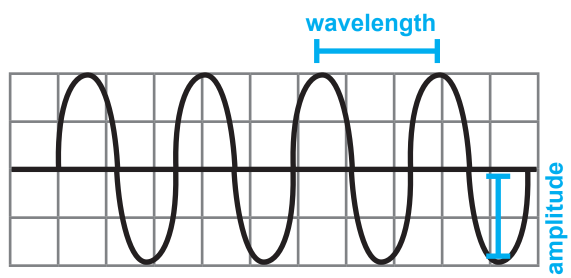
2.a. Waves and Light Answer Key (2/3)

2. Answer the following questions about the waves shown below.

Wave 3



Wave 4



a. Label the amplitude and wavelength for each wave.

b. Which wave has a longer wavelength?

Wave 4

c. Which wave has a higher frequency? How do you know?

Wave 3, because the wavelength is shorter

d. Which wave transfers more energy? How do you know?

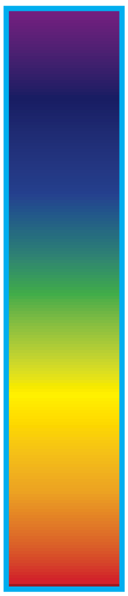
Wave 3, because it has a higher frequency

LESSON 2

Name________________________________ Date___________ Period _____

2.a. Waves and Light Answer Key (3/3)

3. Fill in the table below with information about the color spectrum.

Color	**Energy Levels** (Label the lowest and highest)	**Frequency** (Label the lowest and highest)	**Wavelength** (Label the shortest and longest)
Ultraviolet	**highest**	**highest**	**lowest**
	**lowest**	**lowest**	**highest**
Infrared			

4. What is at least one reason the light from a colored laser is different from the light from a flashlight with white light?

Colored laser light has light with only a single waveform. WHite light has light from mnay different wavelengths.

LESSON 3 Light Propagation

Lesson Objectives
Students will be able to:
- explain that light travels in a straight line and spreads out as it moves away from its source.
- explain the difference between absorption and transmission.

Time Required
One 50-minute class period

Materials
Per classroom:
- (1) flashlight
- (1) mini Mag Light (able to stand up)
- (3) index cards (any size)
- binder clips
- (1) hole punch
- (1) ruler
- **(Optional)** computer with projector
- Engineering Design Process poster

Per team:
- (1) flashlight
- about of square foot of each:
  - aluminum foil
  - plastic wrap
  - wax paper
  - cardboard
  - paper

Per student:
- (1) colored pencil
- (1) pencil
- engineering notebook
- Engineering Design Process slider

Standards Addressed
- Next Generation Science Standards: MS-PS4-2, MS-ETS1-1
- Common Core State Standards – Mathematics: 6.SP.B.5, 6.SP.B.5.A, 6.SP.B.5.B, 8.EE.A.4

Key Terms
1. absorption, transmission

Lesson Summary
Students explore some of the basic properties of light. They observe that light travels in a straight line, spreads out as it moves away from its source, and interacts differently with different surfaces. Students explore absorption and transmission of light using different materials and relate their learning to the engineering design challenge.

Background
Teacher Background
The content of this lesson will depend largely on the students' prior knowledge of waves and light. If students have already learned about waves in the course, the wave activities in this lesson can be skipped or reviewed more briefly. If students do not have exposure to waves (especially wavelength, frequency, and amplitude), complete the activities as they are presented below.

Real-World Examples:
- **Absorption:** Difference between dark and light colored clothing and heat transfer. Lighter clothing reflects light and darker clothing absorbs light. When it absorbs the light, it absorbs the energy from the light and the increase in energy makes the clothes warmer.
- **Transmission:** Sunscreen works because ultraviolet radiation is not transmitted through sunscreen. Visible light is transmitted, so we can still see our skin with sunscreen on, but UV rays cannot go through.
- **Reflection:** Light reflected off a lake or mirror.

Before the Activity
- Prepare for demonstrations. For the light travels in a straight line demo, punch a hole in the center of three index cards.
- Gather and cut materials for students' tests of absorption and transmission. Possible materials include: aluminum foil, plastic wrap, lined paper, wax paper, cardboard. NOTE: Make sure to have a variety of materials that absorb and transmit light so students are able to see multiple examples of both absorption and transmission.
- **(Optional)** Print copies of *3.a. Absorption/Transmission/Reflection Data Table* for students to attach in their engineering notebooks (1 per student).

Classroom Instruction
Introduction
1. **Develop more questions for the client. Say:** *As you know from the previous lessons, you will be working to produce a solution for a client, so you'll need to communicate back and forth with the client as questions and ideas come up. We have one letter from the client and have identified some questions you might have, but there is probably a lot more information you would like to have before starting the challenge. This is your opportunity to think of more questions you'd like the client to answer.* Instruct students to add to their list of questions for the client. They should add to their questions to the worksheet *1.a. Problem Scoping - Section 2.* **Say:** *I'll be sharing our questions with the client later today and will let you know when I hear back. Today, we're going to continue to learn some of the science that we'll need to know to solve the client's problem.*

2. **Identify where they are in the engineering design process. (Learn)** **Ask:** *What phase of the engineering design process do you think we will be using today? Why?* Refer students to their EDP sliders. Remind students that they are learning about light and how it interacts with objects to help them complete the engineering design challenge of creating a laser security system.

Activity

3. **Complete a K-W-H-L Chart.** Tell students they are going to think about some things they have observed or already know about light. Model how to set up a K-W-H-L chart and direct students to create a chart in their engineering notebooks. Tell students they are going to work individually to fill in the first two columns of the chart. In the K (What I **K**now) column, they should record things they know about light. In the W (What I **W**ant to Know) column, they should record things they want to know about light. Give students several minutes to think and record their ideas individually. Then, give students several minutes to discuss their ideas with their teams, recording team responses in another color. Ask each team to share out at least one thing they know and one thing they want to know about light; record student ideas on the board or a piece of poster paper. After every team has had a chance to share, tell students they are going to work with their teams to brainstorm how they could find out what they want to know. They should record their ideas in the H (**H**ow I Could Find Out) column of the chart. Explain that some of the ideas may be tested in this lesson, but some of the students' questions and test ideas will likely still remain after the lesson.

Demonstrations: How does light travel?

4. **Introduce the demonstrations.** Tell students that demonstrations will help them find answers to some of the questions they had about light and some questions they might not have thought of. For each demonstration, share the question with students and ask if any students had recorded that question in their K-W-H-L chart. If students did not record the question, direct them to add it to their chart. **Ask:** *Did anyone have an idea for how we could test that question?* If the ideas are appropriate and materials are available, use a student-generated idea for the test. If students do not have an appropriate or feasible idea for testing the question, conduct the tests described below or a similar alternative. Utilize student volunteers in demonstrations whenever possible. Following each demonstration, discuss what the demonstration showed about light and record in the L (What I **L**earned) column of the chart. The most important conclusions are shown in bold print for each demonstration, and you should ensure that students record these conclusions in their engineering notebooks.

5. **Demonstrate that light travels in a straight line.** Stand up three index cards (punched with a hole in the center of each) vertically on a table using binder clips. Ensure they are in a straight line and equidistant from each other. Have a volunteer position the flashlight at one end of the row of cards, and turn it on with the light pointed at the center of the first card.

Assessments

Pre-Activity Assessment
Examine students' K-W-H-L charts to see what information they record in the K (What I Know) and W (What I Want to Know) columns, noting any misconceptions that will need to be addressed.

Activity Embedded Assessment
Read students' engineering notebooks to see what conclusions they drew from the light demonstrations and absorption/transmission activity.

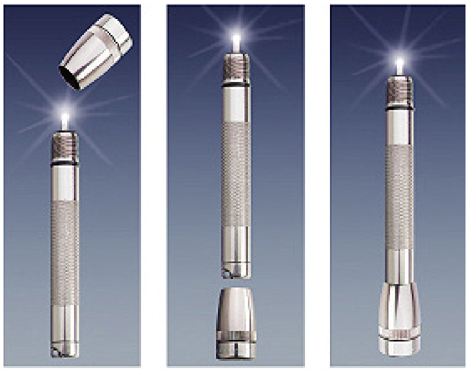
Post-Activity Assessment
Read students' engineering notebook responses to the following questions: *How will your knowledge of light absorption and transmission inform your laser security system design? How would you adjust your design depending on what is in the room? What do you want to remember about light for when you design your security system?* Look for connections between the science content information and the engineering design challenge.

DUPLICATION MASTERS

- 3.a. Absorption/Transmission/ Reflection Data Table

Students should be able to see the light go through all three cards and hit the surface behind the last card. Move the card in the middle so the hole is not aligned with the others. The light should be visible on the middle index card.

6. **Demonstrate that light spreads out as it moves away from the source.** Have a volunteer shine a flashlight at a wall or other surface. Move the light source close to the surface and ask students to observe the light on the surface. Move the light source farther away from the surface and ask students to make observations. As students share observations, direct their attention to the area illuminated by the light.



7. **Demonstrate that light travels in all directions.** Remove the top of a Mag light and place it on the opposite side of the light, forming a base, so the Mag lite can stand up (see image). Turn on the light, revealing a point source. **Ask:** *What do you observe about the light?* They should notice a sphere of light around the point source.

8. **Discuss how fast light travels. Ask:** *How fast does light travel?* Tell students that light can travel from the sun to Earth in about 500 seconds. The Earth is 149,597,870,700 meters from the Sun, so using division, you can determine how fast the light is moving. 149,597,870,700 meters/500 seconds = 299,195,741.4 meters per second. To reinforce how fast this is, remind students of the length of a meter and explain that light is able to travel almost 300,000,000 meters every second. Explain that since these numbers are so large, they are often expressed with scientific notation. **(Optional)** Compare the speed of light to speed of sound with examples like thunderstorms and a person clapping across a field. **Light travels very fast: $3x10^8$ m/s.**

9. **Discuss how light interacts with objects or surfaces. Ask:** *How does light interact with objects or surfaces?* After sharing this question with students, explain that this is the topic of the lab. **Say:** *You will explore this question in your teams.*

Absorption, Transmission and Reflection

10. **Review safety.** Tell students that they need to use the flashlights safely and responsibly, which includes never shining the light at someone's face. Tell students that the flashlights are not dangerous, but that they will be working later with laser pointers, which are dangerous, so they need to practice safety habits.

11. **Connect to engineering design challenge.** Remind students that in the engineering challenge, they will be working with light in a room with a display of artifacts and possibly additional objects as well. Explain that they

are going to explore what happens when light hits the materials that might be present in the room.

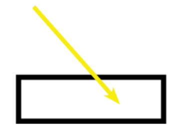
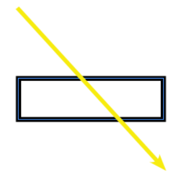
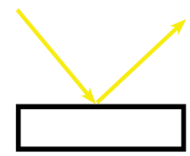
12. **Discuss the activity instructions.** Instruct students to create a data table in their engineering notebooks or distribute printed tables of the *3.a. Absorption/ Transmission/Reflection Data Table* for students to attach to their engineering notebooks. The first column should be labeled "Material," and the second column should be labeled "Observations." Tell students they will work with their teams to make observations about what happens when they shine a flashlight at different materials. They will be able to select from the available materials (aluminum foil, plastic wrap, lined paper, wax paper and cardboard) and can also identify different materials they would like to test in the classroom. As a team, they will select a material, record the material name, shine the flashlight on the material, and record what they observe. Every student should record observations in their individual engineering notebooks. Remind students that they should focus their observations on what happens to the light, considering their knowledge about how light travels. Encourage students to make detailed observations that show how the interaction of light differs based on the material being tested. Depending on time, specify a certain number of materials students should test. Give students some time to explore and record observations.

13. **Discuss observations as class. Ask:** *What were some differences you observed when you shined the light through different materials? Why do you think light behaved differently with the different materials? What properties of the materials seem to affect how light interacts with them?*

14. **Review the vocabulary.** As students share their observations and reveal that sometimes light went through an object while other times it did not, introduce the vocabulary words absorption and transmission. Instruct students to make a K-I-M chart in their engineering notebooks, as shown below.

LESSON 3

Light Propagation

Key Word	Information (Definition)	Memory Cue	Real-World Example
absorption	light does not pass through an object; energy is transferred from the light to the particles of the object		dark clothing on a sunny day
transmission	light passes through an object, so you can see it on the other side		glass window
reflection	light bounces off the surface of the object		image in mirror

Closure

15. Connect to the EDC. Ask: *How will your knowledge of light absorption and transmission inform your laser security system design? How would you adjust your design depending on what is in the room? What do you want to remember about light for when you design your security system?* Direct students to record their answers in their engineering notebooks for later use.

LESSON 3

Name________________________________ Date____________ Period _____

3.a. Absorption/Transmission/Reflection Data Table

Material	Observation

LESSON 4 Intro to Reflection and Refraction

Lesson Objectives
Students will be able to:
- define reflection and refraction.
- identify different types of lenses and how light acts when it passes through them.

Time Required
One 50-minute class period

Materials
Per classroom:
- Engineering Design Process poster

Per team:
- (1) flat lens
- (1) convex lens
- (1) concave lens
- (1) plane (flat) mirror
- (1) concave mirror
- (1) flashlight
- (1) laser pointer
- (1) ruler

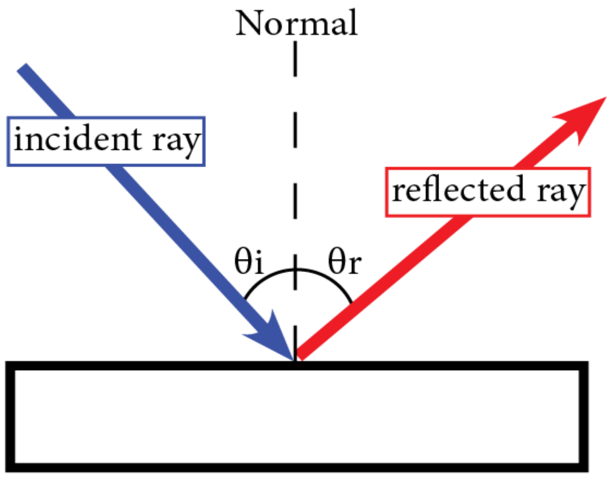
Per student:
- (1) pencil
- engineering notebook
- Engineering Design Process slider

Standards Addressed
- Next Generation Science Standards: MS-PS4-2
- Common Core State Standards – Mathematics: 6.SP.B.5, 6.SP.B.5.A, 6.SP.B.5.B

Key Terms
reflection, refraction, prism, mirror, lens, convex, concave

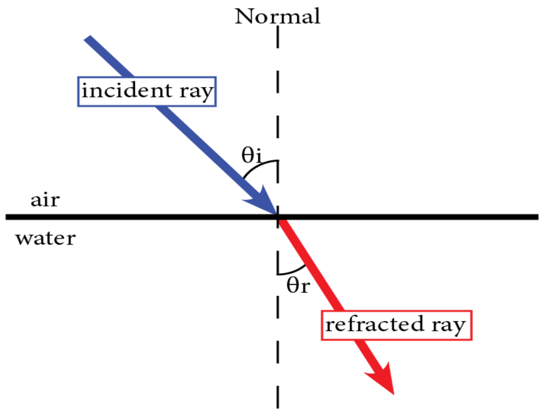
Lesson Summary
This lesson introduces students to reflection and refraction of light. Through hands-on activities, students observe light as it interacts with mirrors and lenses. They learn that light behaves differently depending on the medium with which it is interacting. Students consider how mirrors and lenses can be of use to them in the engineering design challenge of creating a laser security system.

Background
Teacher Background
Reflection occurs when light bounces off a surface, and the light will be reflected in a predictable manner according to the law of reflection. According to this law, when light reflects off a surface, the angle of incidence is equal to the angle of reflection. In the image shown below, the incident ray, or the ray of light approaching the mirror, is shown in blue. The reflected ray, or the ray of light leaving the mirror, is shown in red. Where the ray strikes the mirror, a line drawn perpendicular to the surface of the mirror is the normal line, shown with the dotted line. The angle between the incident ray and the normal is the angle of incidence, and this angle is equivalent to the angle between the reflected ray and the normal, or the angle of reflection.



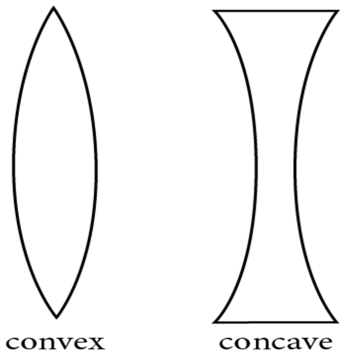
Refraction occurs when a light wave passes between two media. As the light moves through a different medium, the speed of the light changes, causing the light to bend. If the light passes from a medium in which it travels slow to a medium in which it travels fast, the light refracts away from the normal. This is the case for an archer fish that is underwater and is trying to shoot an insect in the air with a stream of water.

In contrast, if the light passes from a medium in which it travels fast to a medium in which it travels slow, the light refracts toward the normal (see image). For example, if a pencil or other straight object is placed in a glass of water, the object will appear to bend at the water's surface.

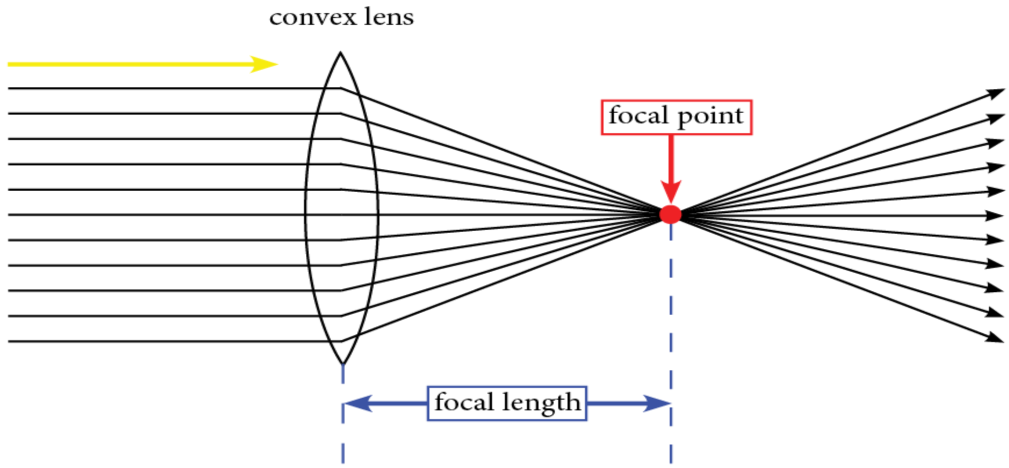


Intro to Reflection and Refraction

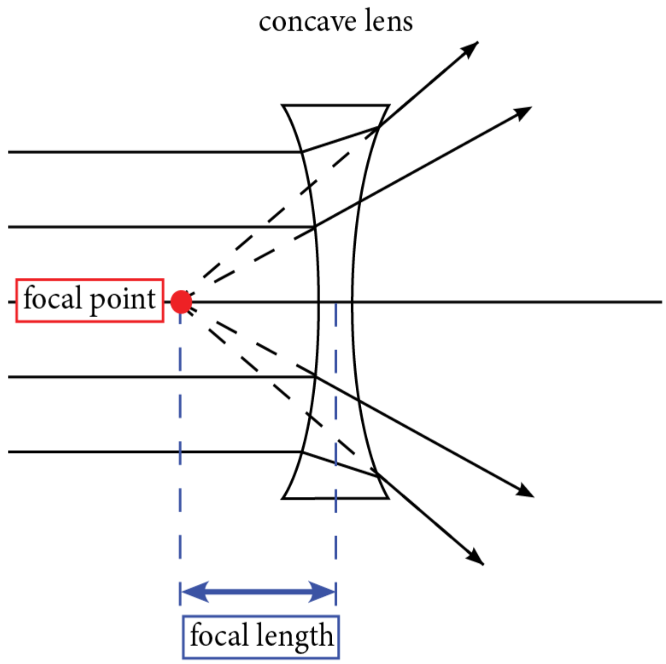
The differences between convex lenses and concave lenses arise because of their shape.



When light travels through a **convex** lens, it focuses at a certain focal point. The focal length of a lens depends on the index of refraction of the glass, the curvature of the surfaces, and the medium the lens is in (pictured below). Magnifying glasses and glasses for farsighted people are examples of convex lenses.



When light travels through a **concave** lens, it spreads out and diverges away from the focal point. Peepholes in doors and eyeglasses for near-sighted people are examples of concave lenses.



Assessments

Pre-Activity Assessment
Attend to student responses to the questions about mirrors and lenses (*Where have you seen similar materials in your lives? What do you know about these items?*), noting any misconceptions that will need to be addressed in the lesson.

Activity Embedded Assessment
Read students' observations about mirrors and lenses in their engineering notebook data tables.

Post-Activity Assessment
Read students' reflection and refraction K-I-M chart in their engineering notebooks. Read students' engineering notebook responses to the following questions: *How could you use a mirror in your security system design? Why would that be helpful? How could you use a convex or concave lens in your design? Why would that be helpful?* Look for connections between the science content information and the engineering design challenge.

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- 4.a. Mirrors and Lenses Observations

LESSON 4

Intro to Reflection and Refraction

Laser Safety: Lasers have high levels of power and, therefore, can be dangerous to human tissue, especially eyes. In this unit, students will be working with low power lasers that are relatively safe. However, they should not shine the light at eyes. Lasers can cause damage to human tissue by thermal damage (burns), and photochemical damage (the light causes a chemical reaction). For visible lasers, human blink reflex will protect eyes because the person will be able to see the light and be able to close their eyes before the laser can damage their eyes. However, laser light outside the visible spectrum can be especially dangerous because the person cannot see the light and may not notice quickly enough the laser light or the damage to their eyes.

Before the Activity

- Create sets of materials for each team of students to facilitate efficient distribution.
- Make copies of duplication master (1 per student).

Classroom Instruction

Introduction

1. **Situate learning in engineering design context. Say:** *We're going to keep working on the engineering design challenge brought to us by the client. We need to keep learning more so we can design our security systems, and today's activities will help prepare us for the challenge. Today, we're going to start working with the materials we will use in the challenge so we can learn about how they perform.* Show students a lens and a mirror. **Ask:** *Where have you seen similar materials in your lives?* Possible responses include bathroom mirrors, mirrors in cars, eyeglasses, cameras, etc. **Ask:** *What do you know about these items?* Explain to students that they will be learning more about these materials in this lesson.

2. **Identify where they are in the engineering design process. (Learn)** **Ask:** *What phase of the engineering design process do you think we will be using today? Why?* Refer students to their EDP sliders. Remind students that they are learning about the properties of light to help them fulfill the client's wishes of having a laser security system.

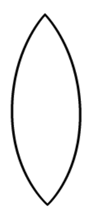
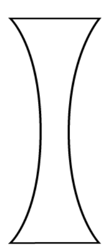
Activity

3. **Discuss safety.** Tell students that they will be using mirrors, flashlights, and lasers throughout the course of the unit. Discuss careful handling of mirrors to prevent breaking them, and instruct students to use care in handling the edges of the mirrors. Explain that there are many different types of lasers. High power lasers can cause burns and vision loss, so safety is always important to consider when using any kind of laser. Laser pointers have a much lower power (1-5 mW) than the types of lasers that can be used for surgery (30-100 W) or industrial laser cutting (100-3,000 W), but they still have potential to cause vision damage if exposure is prolonged. In this lesson, students will first use flashlights to demonstrate their understanding of the safety requirements. Once they have demonstrated that they understand how to safely use the tools, they will have the opportunity to use a laser pointer. When using the flashlights and laser pointers, students should make sure the light does not shine into anyone's eyes. Because they

will be reflecting light, they will need to be especially careful when using materials that may change the path of the light.

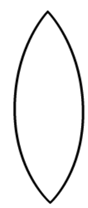
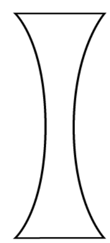
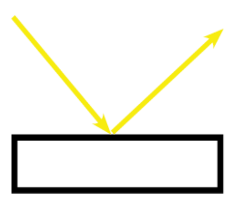
4. **Introduce convex and concave lenses.** Draw diagrams for the whole class on a whiteboard or have students record information in their notebooks. Students will be learning more about the differences, however at this point they should be able to distinguish the lenses from each other.

5. **Introduce the activity.** Distribute copies of the *4.a. Mirrors and Lenses Observations* worksheet. Show students the materials they will be using: a flat lens, convex lens, concave lens, plane (flat) mirror, concave mirror, and a flashlight. Direct students to create a K-I-M chart in their engineering notebooks and fill in the first two rows with information and memory cues about convex and concave lenses. At this point, do not include real-world examples for these two key words because students may be able to identify examples after they have worked with the lenses. Explain that students should follow the instructions printed on the *4.a. Mirrors and Lenses Observations* worksheet, drawing what they see happening to the light and describing what they observe in words. Review safety instructions with students as needed, distribute materials to small teams, dim lights, and give students time to explore the materials and record their findings. As students finish recording their observations and have shown that they can safely use the flashlight, they can use a laser pointer with the same materials to compare.

Key Word	Information (Definition)	Memory Cue	Real-World Example
convex lens	lens that is thicker in the middle and thinner on the edges		
concave lens	lens that is thinner in the middle and thicker on the edges		
reflection			
refraction			

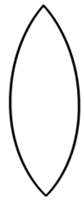
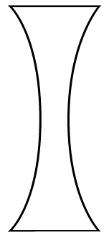
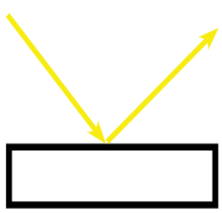
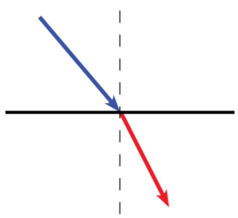
6. **Discuss reflection.** After students have had time to explore materials in their small teams, call the whole class together to discuss their findings.

Ask: *What did you observe when you shined the light at the mirror? How did the plane (flat) mirror compare to the concave mirror? When you changed the angle of the light to the mirror, or the angle of incidence, how did that change the reflection?* Call on students to draw on the board, describe their drawing, and explain why they think that happens to light. As a team, agree on an explanation for what is happening. Introduce the word "reflection" and prompt students to add to their K-I-M charts to include the key word reflection in the third row. They should write the word reflection, define it as when light bounces off a surface, and draw a picture of what it looks like. Model how to draw the light reflecting off a surface.

Key Word	**Information (Definition)**	**Memory Cue**	**Real-World Example**
convex lens	lens that is thicker in the middle and thinner on the edges		magnifying glass
concave lens	lens that is thinner in the middle and thicker on the edges		peephole in a door
reflection	occurs when light bounces off a surface		looking in a mirror to see your image in the morning
refraction			

7. **Discuss refraction. Ask:** *What did you observe when you shined the light at the lenses? How were your observations different for the flat, convex, and concave lenses? Was there a difference in the diameter of the light that traveled through the different lenses? What did you observe when you looked through them? What are some real-world examples of convex and concave lenses we can add to our K-I-M chart?* Use drawings on the board to describe that light is bending differently through the different lenses based on their shape. As a team, agree on an explanation for what is happening. Introduce the word "refraction" and prompt students to fill in the fourth row of their K-I-M chart (as shown below). They should write the word refraction, define it as the bending of light when it moves through a material of different density than air, and draw a picture of what it looks like. Model how to draw refraction, demonstrating the difference between what happens

with a convex and a concave lens (pictured on page 49).

Key Word	**Information (Definition)**	**Memory Cue**	**Real-World Example**
convex lens	lens that is thicker in the middle and thinner on the edges		magnifying glass
concave lens	lens that is thinner in the middle and thicker on the edges		peephole in a door
reflection	occurs when light bounces off a surface		looking in a mirror to see your image in the morning
refraction	the bending of light when it moves through different materials		trying to grab something in the water (spearfishing) and it's in a different location than it actually is

Closure

8. **Connect to the EDC. Ask:** *How could you use a mirror in your security system design? Why would that be helpful? How could you use a convex or concave lens in your design? Why would that be helpful?* Direct students to record their answers in their engineering notebooks for use when they work to complete the design challenge.

LESSON 4

Name_________________________________ Date____________ Period _____

4.a. Mirrors and Lenses Observations (1/3)

Plane (Flat) Mirror: Shine the flashlight at the flat mirror. What do you observe? What happens when you change the angle between the light and the mirror?

Draw or Describe

Concave Mirror: Shine the flashlight at the concave mirror. What is similar and different than shining light at the flat mirror?

Draw or Describe

Concave Lens: Look through the concave lens at an object in the room. Move the lens to different distances from your eye. What do you observe? For example, is the image always clear? If not, when is it clear and when is it blurry? Is the image always the same size? Is the image always upright?

Draw or Describe

Hold the concave lens 3 inches from the table and shine the flashlight 3 inches above the lens. What is the diameter of the light on the table? Trace the image on the Lenses Diameter Record page and record the diameter.

LESSON 4

Name______________________________________ Date____________ Period _____

4.a. Mirrors and Lenses Observations (2/3)

Convex Lens: Look through the convex lens at an object in the room. Move the lens to different distances from your eye. What do you observe? For example, is the image always clear? If not, when is it clear and when is it blurry? Is the image always the same size? Is the image always upright?

Draw or Describe

Hold the convex lens 3 inches from the table and shine the flashlight 3 inches above the lens. What is the diameter of the light on the table? Trace the image and record the diameter.

Flat Lens: Look through the flat lens at an object in the room. Move the lens to different distances from your eye. What do you observe? For example, is the image always clear? If not, when is it clear and when is it blurry? Is the image always the same size? Is the image always upright?

Draw or Describe

Hold the flat lens 3 inches from the table and shine the flashlight 3 inches above the lens. What is the diameter of the light on the table? Trace the image and record the diameter.

Control: Hold the flashlight 6 inches above the paper without a lens. Trace the image and record the diameter.

Compare Lenses: Which lens spreads the light out the most? Which one spread the light out the least?

Name________________________________ Date___________ Period _____

4.a. Mirrors and Lenses Observations (3/3)

Lens Diameter Record

Concave Lens

Diameter: ____________________

Convex Lens

Diameter: ____________________

Flat Lens

Diameter: ____________________

Control

Diameter: ____________________

Lesson 5 Reflection/Refraction Simulation

Lesson Objectives
Students will be able to:
- describe how to use a protractor to measure angles.
- explain the law of reflection.
- explain that the speed of light depends on the medium through which it is traveling and connect this to the angle of refraction.

Time Required
One-two 50-minute class period

Materials
Per classroom:
- computer with projector
- Engineering Design Process poster

Per team:
- **(Optional)** computer or tablet

Per student:
- (1) protractor
- (1) red pencil or marker
- (1) green pencil or marker
- (1) pencil
- engineering notebook
- Engineering Design Process slider

Standards Addressed
- Next Generation Science Standards: MS-PS4-2, MS-ETS1-1
- Common Core State Standards – Mathematics: 4.MD.C.5, 4.MD.C.6, 6.SP.B.5.B, 8.G.A.1, 8.G.A.1.B, 7.RP.A.2, 7.RP.A.2.A, 7.RPA.2.B, 8.G.A.5

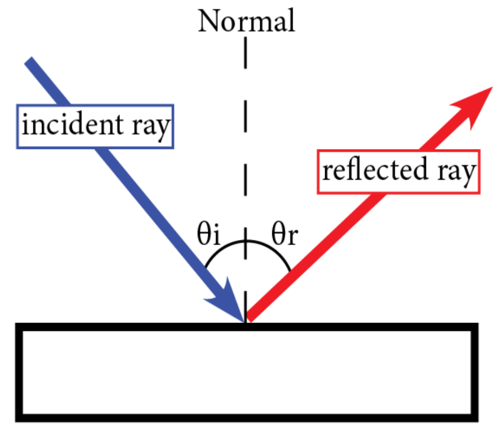
Key Terms
reflection, refraction, normal line, angle of incidence, angle of reflection, angle of refraction, index of refraction

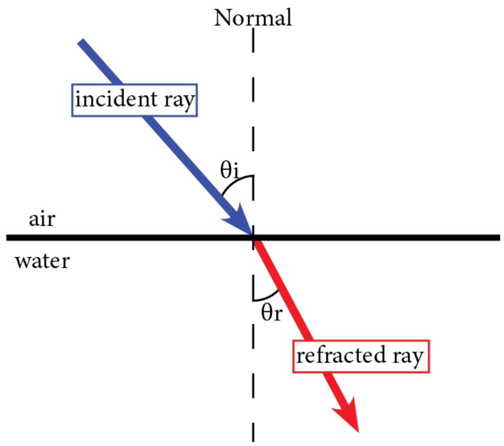
Lesson Summary
In this lesson, students read an email from the client with responses to their questions. Students complete a guided exploration of a simulation. By manipulating variables within the simulation, they discover the law of reflection. They also learn that the angle of refraction is dependent upon the medium through which light is passing, which affects the speed of the light. Students connect this learning back to the engineering design challenge, noting how their new content knowledge can help them plan a successful laser security system design.

Background
Teacher Background
The law of reflection states that light will reflect off a surface at the same angle it hit the surface. The angle of incidence and angle of reflection are equal.

The index of refraction is a material property that describes how light travels through the material. It depends on how fast light travels through the material. It is usually abbreviated as n. For example, in a vacuum, n=1, in water, n=1.33, in glass, n=1.5. The index of refraction is unitless.

- **Normal line:** the line perpendicular to the surface that is drawn from where the light ray hits the surface.
- **Angle of incidence:** the angle between the incoming light ray and a line normal to the surface, shown below as θi
- **Angle of reflection:** the angle between the reflected light ray and a line normal to the surface, shown on the left as θr
- **Angle of refraction:** the angle between the refracted light ray and a line normal to the surface, shown on the right as θr





Before the Activity
- Create client email. A template is available. Consider student questions for the client. It is fine to answer only some of the questions.
- Make copies of the duplication masters (1 per student)
- Check technology. If students are using computers/tablets in teams, make sure they are ready to go. If students are doing the activity as a whole class, make sure projector is working.
- Get familiar with the PhET simulation. Available at: https://phet.colorado.edu/en/simulation/bending-light

Reflection/Refraction Simulation

Classroom Instruction

Introduction

1. **Review the design context.** Remind the students of the engineering design problem and the questions they asked of the client in lesson 2. **Say:** *I sent your questions to the client, and they sent an email with more information. Just like you did with the letter, you're going to read the email and look for the details that you'll need to keep in mind as you move forward on the design challenge. Any criteria, or things that are required for a successful design, should be underlined in green. Constraints, or limits on how you can solve the problem, should be underlined in red.* Give students time to read and annotate the *5.a. Client Email* in their teams, then share out some of the key additional information provided in the email.

2. **Identify where they are in the engineering design process. (Learn) Ask:** *What phase of the engineering design process do you think we will be using today? Why?* Refer students to their EDP sliders. Remind students that they are learning about the properties of light to help them fulfill the client's wishes of having a laser security system.

3. **Review reflection and refraction. Say:** *As we keep working toward creating a laser security system for the client, we continue to learn more and more about light. In our last lesson, we learned the difference between reflection and refraction.* **Ask:** *What is reflection?* Accept student response and clarify as needed. **Ask:** *What is refraction?* Accept student response and clarify as needed. **Say:** *Today, we will learn even more about reflection and refraction and will make some measurements that will help inform your engineering designs.*

Activity

4. **Practice with the protractor.** Demonstrate how to measure angles with a protractor. Students may need a reminder of what angles are and that angles are measured in degrees. If necessary, have students practice measuring using protractors by completing the *5.b. Protractor Practice* worksheet. This can be done either individually or in teams.

5. **Conduct PhET Simulation.** Distribute the *5.c. Bending Light Simulation* worksheet. NOTE: This activity requires use of a computer or tablet. There are two options for this activity. Option 1 requires Internet access for at least pairs of students. Option 2 requires Internet access for the teacher computer or tablet.

   OPTION 1
   - **Conduct PhET Simulation for individuals or pairs.** If computers or tablets are available, students can work with partners or their teams to complete the activity. Students will use the simulation at https://phet.colorado.edu/en/simulation/bending-light to work through the worksheet at their own pace. Alternatively, the bending light simulation can be found on the PhET website under the "Physics" and "Light & Radiation" tab.

Assessments

Pre-Activity Assessment
Assess students' understanding of criteria and constraints based on their client email annotations. Check understanding of reflection and refraction in student responses to the following prompts: *Who can describe reflection? Who can describe refraction?*

Activity Embedded Assessment
Examine students' responses on the *5.c. Bending Light Simulation* using the *5.d. Bending Light Simulation Answer Key*.

Post-Activity Assessment
Read students' engineering notebook responses to the following questions: *How could you use this new information in your design for a laser security system? What do you want to remember from today that will help you make design plans?* Look for connections between the science content information and the engineering design challenge.

DUPLICATION MASTERS

- **(Optional)** 5.b. Protractor Practice
- 5.c. Bending Light Simulation

EDUCATOR RESOURCES

- 5.a. Client Email Template
- 5.d. Bending Light Simulation Answer Key

Reflection/Refraction Simulation

- **Discuss PhET Simulation as a class.** After students have had time to complete the PhET simulation and associated worksheet, bring the whole team together to discuss the key points they should have learned from the simulation. **Ask:** *How did the angle of incidence compare to the angle of reflection?* Explain that this is called the law of reflection. **Ask:** *What did you discover about light moving from one type of material to another? What types of materials will light move through in the security system?* Ensure that students connect the simulation of light moving from one medium to another to the light moving through different types of lenses.

OPTION 2

- **Conduct PhET Simulation as a whole class activity.** If computers are not available for each pair or team, this can be a whole class activity. The same simulation is used from https://phet.colorado.edu/en/simulation/bending-light. Students will be introduced to several new vocabulary words during the simulation. Have them record these in their notebooks as they come up in the discussion, either just the definitions or in a chart. Use the simulation to demonstrate the meanings of the words: angle of incidence, angle of reflection, angle of refraction, index of refraction, normal line.

- **Explore the simulation.** Using the “more tools” tab, project the simulation so the whole class can see it. Show students the variables that can be changed in the simulation and the measurements that are possible. Have students work individually or in their teams to make a list of questions they can answer with the simulation or measurements they think would be interesting. Have students share their ideas and record them so the whole class can see and refer back to them later. If they do not bring them up, prompt students with the questions, *What will happen to the angle of reflection if we change the angle of incidence? What will happen if we change the material? What happens to the speed of light as it goes into a different material?* Use the simulation to answer the students’ questions. Have them make data tables in their notebooks to record the data (example chart shown on the next page). Important things to emphasize:
  - The angle of reflection is always the same as the angle of incidence (this is the law of reflection).
  - When the light travels into a different material, its speed changes. If it travels to a material with a higher index of refraction, it bends towards the normal line. If it travels into a material with a lower index of refraction, it bends away from the normal.

  If time allows: Use the “Prisms” tab to explore how light behaves in prisms and lenses. In this simulation, concave and convex lenses can be constructed by putting together pieces of the prisms.

- **Wrap up discussion of the PhET Simulation.** Wrap up with a discussion about what the students learned from the simulation.

Material 1	Material 2	Speed of light in material 1	Speed of light in material 2	Angle of incidence	Angle of refraction
air (n = 1)	glass (n = 1.5)			15°	
air (n = 1)	glass (n = 1.5)			30°	
air (n = 1)	glass (n = 1.5)			45°	
air (n = 1)	glass (n = 1.5)			60°	
air (n = 1)	glass (n = 1.5)			75°	

Closure

6. **Connect to the EDC. Ask:** *How could you use this new information in your design for a laser security system? What do you want to remember from today that will help you make design plans?* Direct students to record their answers in their engineering notebooks for use when they work to complete the design challenge.

5.a. Client Email Template

To: Engineering Teams

From: lou.richards@lasersecure.com

Re: Laser Security System

Hello Engineering Teams,

We received your questions about the laser security system that we need designed. Thank you for thinking about the problem and asking thoughtful questions. We are not able to answer all of them right now, but we will give you more information as it becomes available.

[Provide information here based on students questions. Information could include:

- Materials they can use: Students will have 3 flat mirrors, 1 concave mirror, 1 concave lens, 1 convex lens, 1 flat lens, a laser pointer, binder clips to support mirrors and lenses, protractors, and rulers.
- Time they have: Students will have 2-3 days for initial design (including planning, building, and testing) and 1 day to redesign. (This could be adapted slightly if time allows).
- Size of the room to be secured: Students will make prototypes that are 40 cm x 50 cm.
- Type of artifacts, cities to be visited by the traveling exhibit, size of artifacts, etc.: Choose these based on the interests of the students.

Include additional information as needed to fit your context.]

Thanks,

Lou A. S. E. Richards

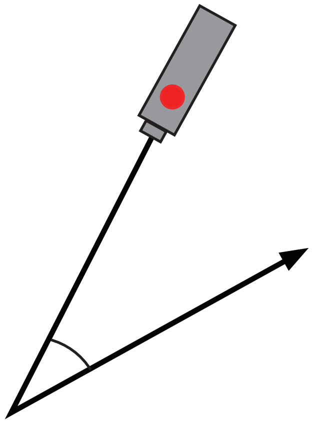
Laser Secure

Name________________________________ Date____________ Period ______

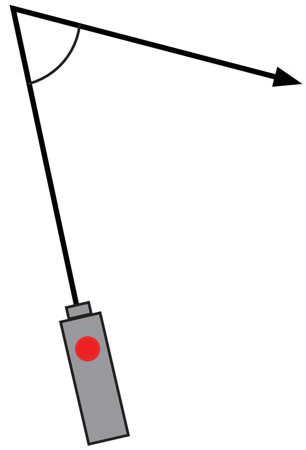
5.b. Protractor Practice (1/2)

Directions: Measure the angle marked in each picture below. Write the angle measure next to each angle.

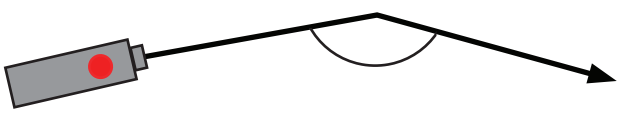
A)



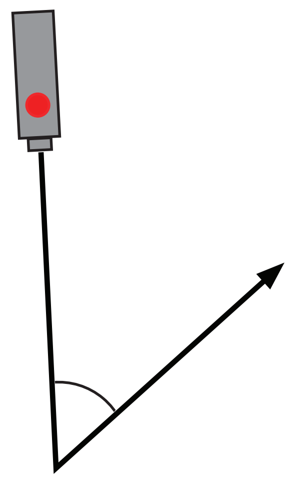
B)



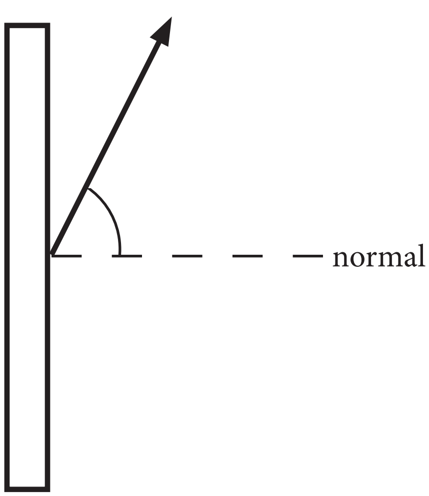
C)



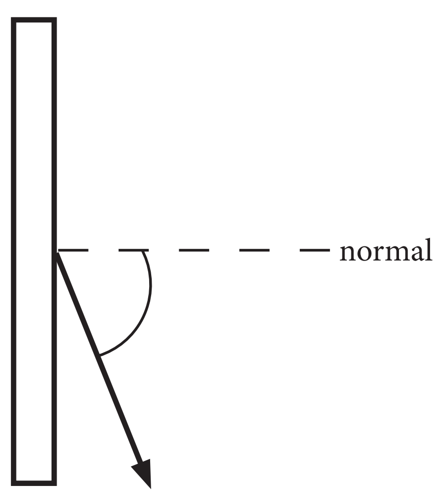
D)



E)



F)

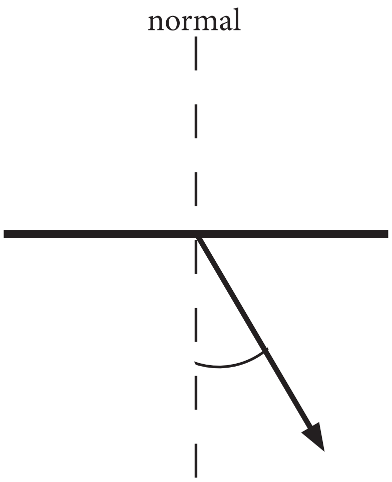


LESSON 5

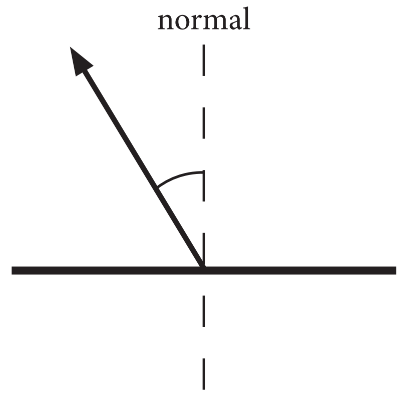
Name____ Date____________ Period ______

5.b. Protractor Practice (2/2)

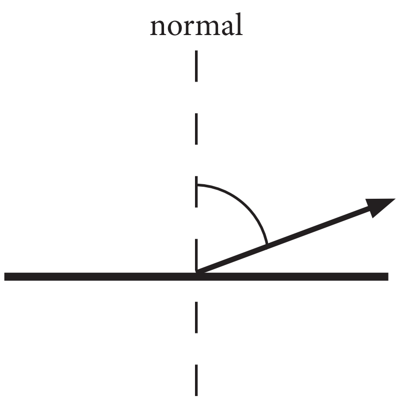
G)



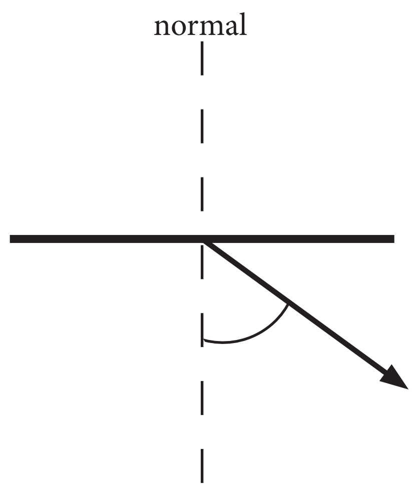
H)



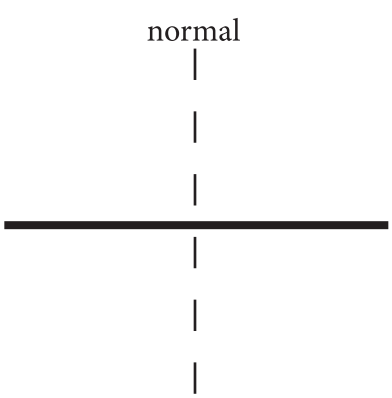
I)



J)



K) Draw a 35° angle from the normal line



L) Draw a normal line and a 70° angle from that normal line

Name_________________________________ Date____________ Period _____

5.c. Bending Light Simulation (1/4)

Go to the simulation at https://phet.colorado.edu/en/simulation/bending-light.
Click on the picture of the simulation. Click on "More Tools."

Introduction/Exploration

1. Explore the simulation to get comfortable with the controls. Record 3 things you observe.

   a. ____

   b. ____

   c. ____

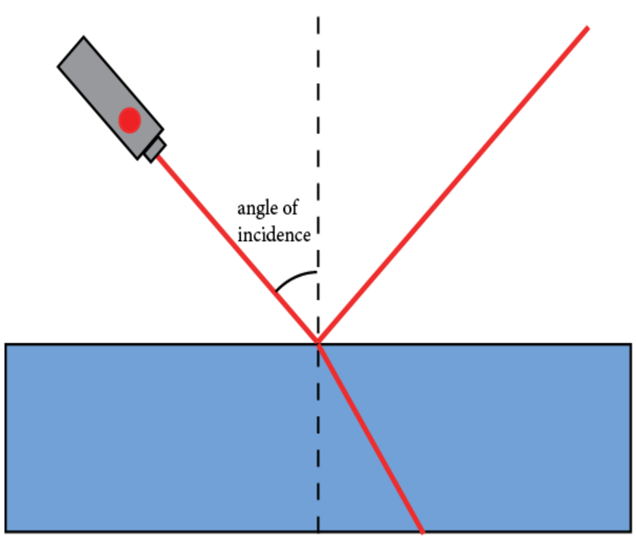
2. Refresh the screen to the original settings by clicking the orange refresh button in the bottom right corner. Turn on the laser. What do you observe? Use the words reflection and refraction as needed.

3. What is the dotted vertical line called?

4. Why is the dotted vertical line important?

Part 1: Changing Angles

5. The angle between the incident ray and the normal line is called the **angle of incidence**. Measure this angle using the protractor in the simulation and record the value. Place the protractor on the horizontal surface. Make sure 90° is lined up with the surface.

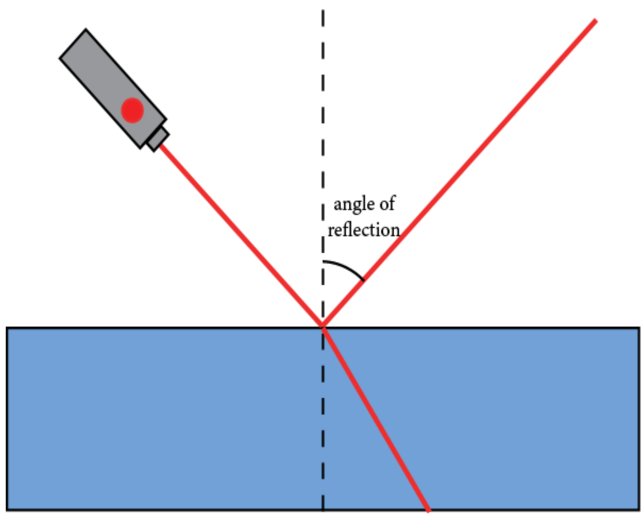


Angle of incidence: __________degrees

Name______________________________ Date__________ Period _____

5.c. Bending Light Simulation (2/4)

6. The angle between the normal line and the reflected ray is called the **angle of reflection**. Measure this angle using the protractor in the simulation and record the value.



Angle of reflection: ________degrees

7. How do the angle of incidence and the angle of reflection compare? Is one larger? Smaller? Are they the same?

8. What happens when you change the angle of incidence?

9. All angles should be measured from ________________________________.

10. Move the laser to five different angles. Record the angle of incidence and angle of reflection in Data Table 1.

Data Table 1

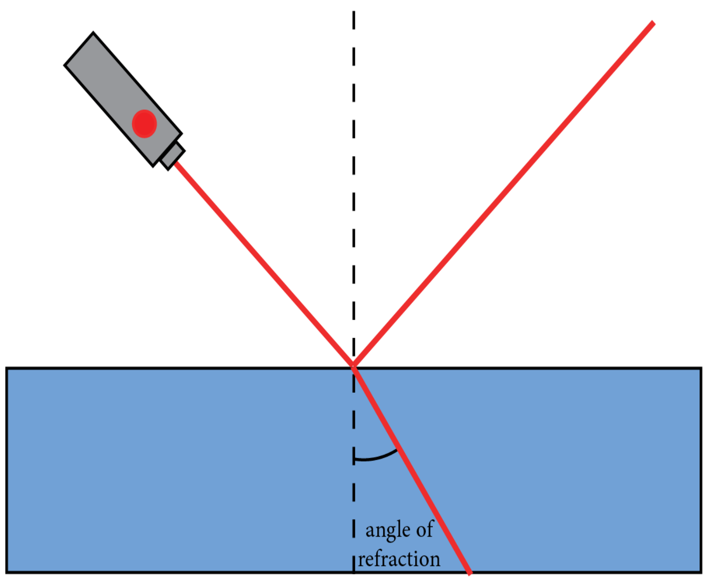
Angle of incidence	Angle of reflection	How do they compare?

Name_______________________ Date__________ Period _____

5.c. Bending Light Simulation (3/4)

Part 2: Changing Materials

11. The angle of refraction is the angle between the refracted ray and the normal line. What is the angle of refraction when the **angle of incidence is 40°**?



Angle of refraction: __________degrees

12. The **index of refraction** (n) is a given value for a material that depends on how fast light moves through that material. Complete Data Table 2 by changing the materials in the simulation. Material 1 is on top, and Material 2 is on the bottom. Use the speed tool on the left to measure the speed of light. Point directly on the laser beam.

Data Table 2

Material 1	Material 2	Speed of light in material 1	Speed of light in material 2	Angle of incidence	Angle of refraction
air (n = 1)	water (n = 1.33)			40°	
air (n = 1)	glass (n = 1.5)			40°	
water (n = 1.33)	air (n = 1)			40°	
water (n = 1.33)	glass (n = 1.5)			40°	
glass (n = 1.5)	water (n = 1.33)			40°	
glass (n = 1.5)	air (n = 1)			40°	

Name_________________________ Date__________ Period _____

5.c. Bending Light Simulation (4/4)

13. What does n represent?

14. When light travels from a material with a larger index of refraction to a smaller one, it behaves differently than when it travels from a material with a smaller index of refraction to a larger one. Use the data you collected from the simulation to fill in Data Table 3.

Data Table 3

When light travels from:	For example:	The speed of the light_______ (increases, decreases, stays the same)	The angle of refraction is __________ (less than, greater than, the same as) the angle of incidence
higher n to lower n (1.33 to 1)	water to air, glass to water, glass to air		
lower n to higher n (1 to 1.5)	air to water, air to glass, water to glass		

15. Based on the information in Data Table 3, I can make the claim that when light moves from a material with **higher** n to **lower** n, the light ________________________________ (slows down, speeds up, stays the same speed).

16. Based on the information in Data Table 3, I can make the claim that when light moves from a material with **lower** n to **higher** n, the light ________________________________ (slows down, speeds up, stays the same speed).

17. Based on the information in Data Table 3, I can make the claim that when light moves into a material with **lower** n, the light ________________________________ (bends away from the normal line, bends toward the normal line, does not bend).

18. Based on the information in Data Table 3, I can make the claim that when light moves into a material with **higher** n, the light ________________________________ (bends away from the normal line, bends toward the normal line, does not bend).

5.d. Bending Light Simulation Answer Key (1/4)

Go to the simulation at https://phet.colorado.edu/en/simulation/bending-light.
Click on the picture of the simulation. Click on "More Tools."

Introduction/Exploration

1. Explore the simulation to get comfortable with the controls. Record 3 things you observe.

   a. **Answers will vary**

   b. **Answers will vary**

   c. **Answers will vary**

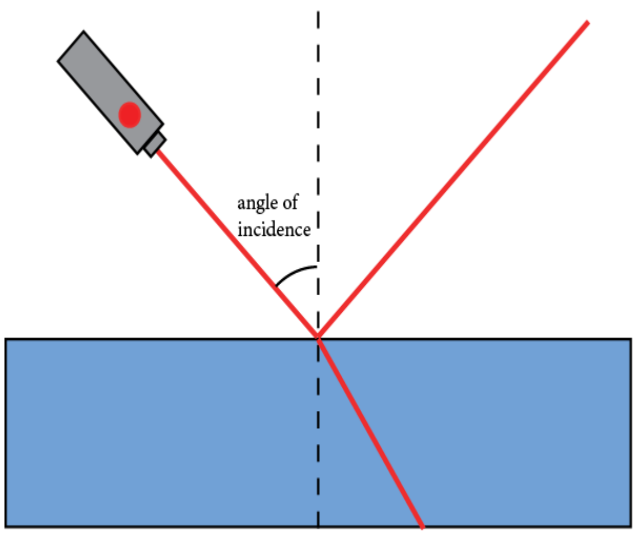
2. Refresh the screen to the original settings by clicking the orange refresh button in the bottom right corner. Turn on the laser. What do you observe? Use the words reflection and refraction as needed.
   When the laser light hits the surface, it reflects and refracts. The refracted ray is brighter than the reflected ray.

3. What is the dotted vertical line called?
   The normal line.

4. Why is the dotted vertical line important?
   It helps you measure the angles.

Part 1: Changing Angles

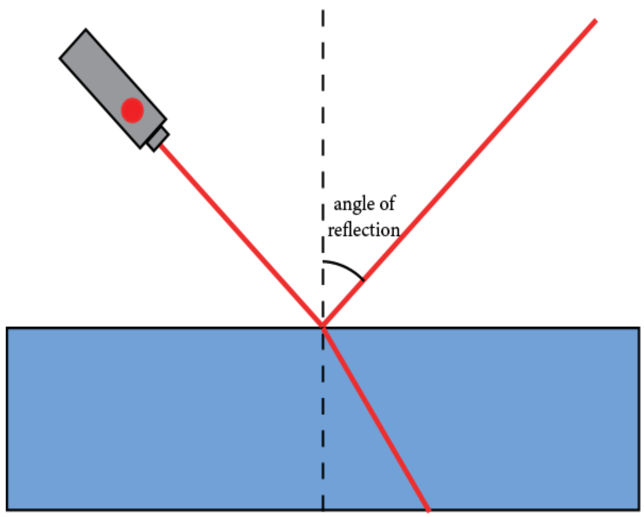
5. The angle between the incident ray and the normal line is called the **angle of incidence**. Measure this angle using the protractor in the simulation and record the value. Place the protractor on the horizontal surface. Make sure 90° is lined up with the surface.



Angle of incidence: ______**45**______degrees

5.d. Bending Light Simulation Answer Key (2/4)

6. The angle between the normal line and the reflected ray is called the **angle of reflection**. Measure this angle using the protractor in the simulation and record the value.



Angle of reflection: ____**45**____degrees

7. How do the angle of incidence and the angle of reflection compare? Is one larger? Smaller? Are they the same?
   They are the same.

8. What happens when you change the angle of incidence?
   The angle of reflection also changes.

9. All angles should be measured from **the normal line**.

10. Move the laser to five different angles. Record the angle of incidence and angle of reflection in Data Table 1.
    Answers will vary, but for each row, the angle of incidence should be the same.

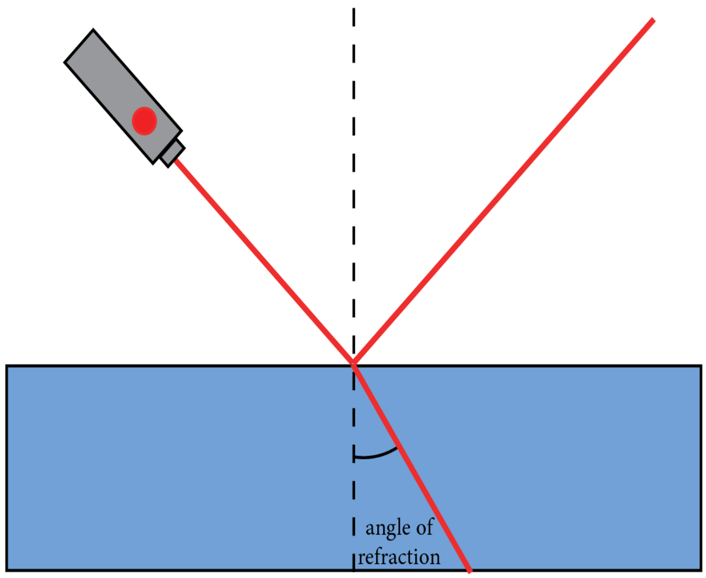
Data Table 1 - Example

Angle of incidence	Angle of reflection	How do they compare?
45°	45°	same
20°	20°	same
60°	60°	same

5.d. Bending Light Simulation Answer Key (3/4)

Part 2: Changing Materials

11. The angle of refraction is the angle between the refracted ray and the normal line. What is the angle of refraction when the **angle of incidence is 40°**?



Angle of refraction: ______28______degrees

12. The **index of refraction** (n) is a given value for a material that depends on how fast light moves through that material. Complete Data Table 2 by changing the materials in the simulation. Material 1 is on top, and Material 2 is on the bottom. Use the speed tool on the left to measure the speed of light. Point directly on the laser beam.

Data Table 2

Material 1	Material 2	Speed of light in material 1	Speed of light in material 2	Angle of incidence	Angle of refraction
air (n = 1)	water (n = 1.33)	1.00 c	0.75 c	40°	29°
air (n = 1)	glass (n = 1.5)	1.00 c	0.67 c	40°	25°
water (n = 1.33)	air (n = 1)	0.75 c	1.00 c	40°	60°
water (n = 1.33)	glass (n = 1.5)	0.75 c	0.67 c	40°	35°
glass (n = 1.5)	water (n = 1.33)	0.67 c	0.75 c	40°	47°
glass (n = 1.5)	air (n = 1)	0.67 c	1.00 c	40°	75°

5.d. Bending Light Simulation Answer Key (4/4)

13. What does n represent?
    The index of refraction.

14. When light travels from a material with a larger index of refraction to a smaller one, it behaves differently than when it travels from a material with a smaller index of refraction to a larger one. Use the data you collected from the simulation to fill in Data Table 3.

Data Table 3

When light travels from:	For example:	The speed of the light________ (increases, decreases, stays the same)	The angle of refraction is ___________ (less than, greater than, the same as) the angle of incidence
higher n to lower n (1.33 to 1)	water to air, glass to water, glass to air	**increases**	**greater than**
lower n to higher n (1 to 1.5)	air to water, air to glass, water to glass	**decreases**	**less than**

15. Based on the information in Data Table 3, I can make the claim that when light moves into a material with **lower** n, the light **increases**.

16. Based on the information in Data Table 3, I can make the claim that when light moves into a material with **higher** n, the light **slows down**.

17. Based on the information in Data Table 3, I can make the claim that when light moves into a material with **lower** n, the light **bends away from the normal line**.

18. Based on the information in Data Table 3, I can make the claim that when light moves into a material with **higher** n, the light **bends toward the normal line**.

LESSON 6

Reflection/Refraction Experiments and Data Collection

Lesson Objectives

Students will be able to:

- use a protractor to measure angles.
- explain their observations of reflection and refraction.

Time Required

One 50-minute class period

Materials

Per classroom:

- Engineering Design Process poster

Per team:

- (1) laser pointer
- (1) flat mirror
- (1) convex lens
- (1) concave lens
- (1) protractor
- (1) ruler or straightedge
- (2) large binder clips
- clay
- **(Optional)** (1) concave mirror

Per student:

- (1) pencil
- engineering notebook
- Engineering Design Process slider

Standards Addressed

- Next Generation Science Standards: MS-PS4-2
- Common Core State Standards – Mathematics: 4.MD.C.5, 4.MD.C.6, 6.SP.A.2, 6.SP.B.5, 6.SP.B.5.A, 6.SP.B.5.B, 8.G.A.1, 8.G.A.1.B

Key Terms

refraction, normal line, angle of incidence, angle of reflection, angle of refraction

Lesson Summary

In this lesson, students apply their learning from the reflection and refraction simulation to a hands-on activity. They conduct controlled experiments to measure angles of reflection and refraction of mirrors and lenses. As they work through a guided lab, students record data they will need for their laser security system prototype design and reflect on how the lab activities will inform their designs.

Background

Teacher Background

In this lesson, students will be measuring and recording values for the angles of reflection and refraction from the lenses and mirrors. They will need this data to complete their plans for their laser security systems in lesson 7. They will need to be careful in their data collection and may need support to make accurate measurements. A duplication master with a paper protractor is provided, and students may mark this protractor for the lab. However, students may also need an additional protractor to make more accurate measurements.

Before the Activity

- Collect the materials needed for the lab.
- Make copies of duplication masters (1 per student).

Classroom Instruction

Introduction

1. **Review reflection and refraction. Say:** *In the last lesson, you completed a simulation to learn more about reflection and refraction of light.* **Ask:** *What were some of the key things you learned through the simulation?* Accept student responses.

2. **Connect to EDC. Say:** *The simulation provided some useful information that you'll be able to use when you design your laser security system. Today, you're going to explore some of the materials that will actually be available for you to use in your security system designs.*

3. **Identify where they are in the engineering design process. (Learn) Ask:** *What phase of the engineering design process do you think we will be using today? Why?* Refer students to their EDP sliders. Remind students that it is important to collect data to make their laser security system.

Activity

4. **Review safety.** Remind students to carefully handle the mirrors to prevent breaking them and to use care in handling the edges of the mirrors. Explain that there are many different types of lasers. Remind students to not point the flashlights and laser pointers at anyone's eyes. Because they will be reflecting light, they will need to be especially careful when using materials that may change the path of the light.

5. **Complete the lab activity.** Explain that students will be working through a lab to collect data that will help them make their laser security system design plan. They will want to carefully measure and record their data

so their security system works as they want it to. Distribute the *6.a. Measuring Reflection and Refraction Lab* worksheets, the *6.b. Paper Protractors* (if needed), and materials, reminding students of the guidelines for using the mirrors and lasers safely, then give students time to work through the lab in their small teams. As students work, circulate around the classroom, reminding students about careful measurement as needed and asking questions about what they are observing about the different materials. **(Optional)** If students need extra support measuring angles, have them use the full circle protractor.

Closure

6. **Answer lab conclusion questions.** As students finish the lab procedures, direct them to answer the conclusion questions in their engineering notebooks:
   - What was the hardest part of this lab? How did you overcome this challenge?
   - What was the most interesting thing you observed in this lab?
   - How did your measurements in this lab compare with your measurements from the simulation in the previous lesson?
   - How will the data you collected in this lab help you with your laser security system plan?

7. **Discuss the lab results**. Have a class discussion about the following questions:
   - How did the results of this investigation compare to the results of the PhET simulation?
   - What do you think might have resulted in any similarities or differences you described?
   - How can we know if any differences are significant enough that we need to do more investigation?

   As students identify discrepancies between their PhET simulation measurements and lab measurements, encourage them to think about measurement error. To help students understand why there is so much error present, display the prisms section of the PhET Bending Light Simulation. Shine the light through a convex and concave lens and show student show even a slight change in the the angle of incidence or where the light shines through the lens affects the angle of refraction.

8. **(Optional) Complete additional laser exploration activities as desired.** Possibilities include laser simulations, laser videos, or activities in class.

9. **Connect to the EDC.** Tell students that in the next lesson they will be making a plan for their security system, so they should be thinking about how they will use the science they have learned to make their plan. If time allows, direct students to record key points they think will be helpful for the design challenge in their engineering notebooks.

Assessments

Pre-Activity Assessment
Assess students' understanding of reflection and refraction based on their responses to the question *What were some of the key things you learned through the simulation?*

Activity Embedded Assessment
Examine students' responses on the *6.a. Measuring Reflection and Refraction Lab* worksheet.

Post-Activity Assessment
Read students' engineering notebook responses to the lab conclusion questions.

DUPLICATION MASTERS

- 6.a. Measuring Reflection and Refraction Lab
- 6.b. Paper Protractor

LESSON 6

Name________________________________ Date____________ Period ______

6.a. Measuring Reflection and Refraction Lab (1/4)

Materials:

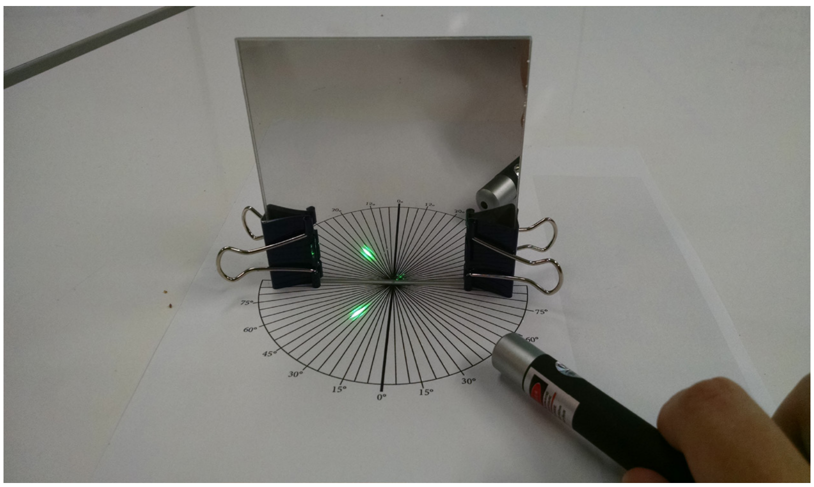
1 laser pointer
1 flat mirror
1 concave lens
1 convex lens
1 protractor
1 ruler or straightedge
Large binder clips
clay

Part 1: Mirrors

Set up and Exploration:

1. Place the flat mirror on the straight line of the paper protractor as pictured below, using a binder clip to support the mirror. The line labeled as 0° is the normal line.

2. Explore the materials and how the laser light interacts with the mirror.

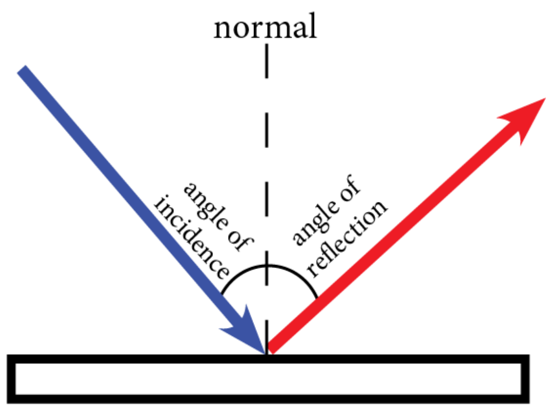


Data Collection:

3. Shine the laser pointer at an angle at the mirror so it hits the mirror at the point where the normal line meets the mirror. Draw dots on the paper protractor where the laser light begins (at the laser pointer) and where the reflected light hits the paper protractor.

4. Use the ruler to connect each dot to the intersection of the normal line and the mirror, showing the path of the laser light. Measure the angle of incidence and the angle of reflection. Record these values in a data table in your engineering notebook as shown below.

Trial Number	Angle of incidence	Angle of reflection
1		
2		
3		
4		



Name_________________________________ Date___________ Period _____

6.a. Measuring Reflection and Refraction Lab (2/4)

5. Change the angle of incidence. Take new measurements and record in your data table.

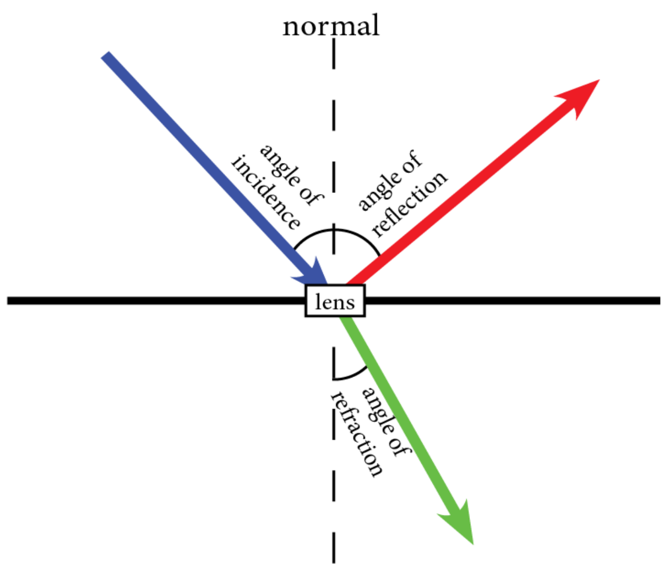
6. How do the angle of incidence and the angle of reflection compare for each of your trials?

7. How will the data you have gathered help you design your laser security system?

Part 2: Concave Lens

8. Replace the mirror with a concave lens on a new paper protractor. Use clay to support the concave lens.

9. Measure the angles of incidence, reflection, and refraction of light interacting with the concave lens. Record in the table below. To measure the angle of reflection, repeat the steps used in part 1 of the lab. To measure the angle of refraction, mark where the laser beam hits the paper after traveling through the lens. Use the ruler to connect the dots along the path of the laser light, and measure with a protractor.



10. Repeat step 9 with additional angles of incidence. Make sure to use both large and small angles.

Trial Number	Angle of incidence	Angle of reflection	Angle of refraction
1			
2			
3			
4			

Name________________________________ Date___________ Period _____

6.a. Measuring Reflection and Refraction Lab (3/4)

Part 3: Convex Lens

10. Replace the concave lens with a convex lens on a new paper protractor. Repeat the steps to measure the angles of incidence, reflection, and refraction with the convex lens. Record your data in the table below.

Trial Number	Angle of incidence	Angle of reflection	Angle of refraction
1			
2			
3			
4			

Part 4: Multiple mirrors

11. Explore using 2 or more mirrors or lens. What happens? Record 3 things your observation with words or pictures.

Part 5: Concave Mirror (optional)

12. Shine the laser pointer at an angle at the mirror so it hits the mirror at the point where the normal line meets the mirror. Draw dots on the paper protractor where the laser light begins (at the laser pointer) and where the reflected light hits the paper protractor.

Trial Number	Angle of incidence	Angle of reflection
1		
2		
3		
4		

Name____________________________________ Date____________ Period ______

6.a. Measuring Reflection and Refraction Lab (4/4)

Part 6: Conclusion

13. What was the most challenging part of this lab? How did you overcome this challenge?

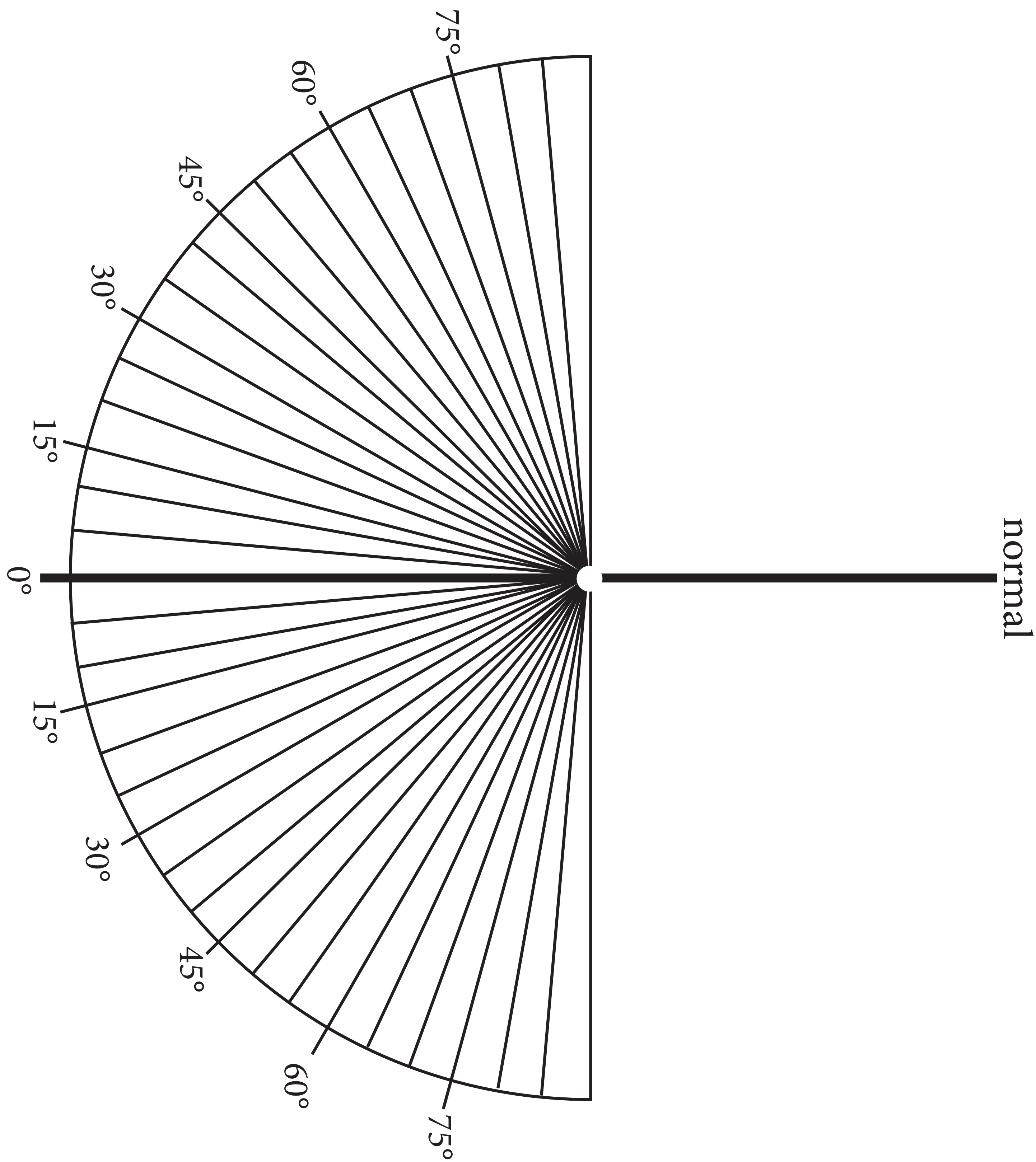
14. What was the most interesting thing you observed in this lab?

15. How did your measurements in this lab compare with your measurements from the simulation in the previous lesson?

16. How will the data you collected in this lab help you with your laser security system plan?

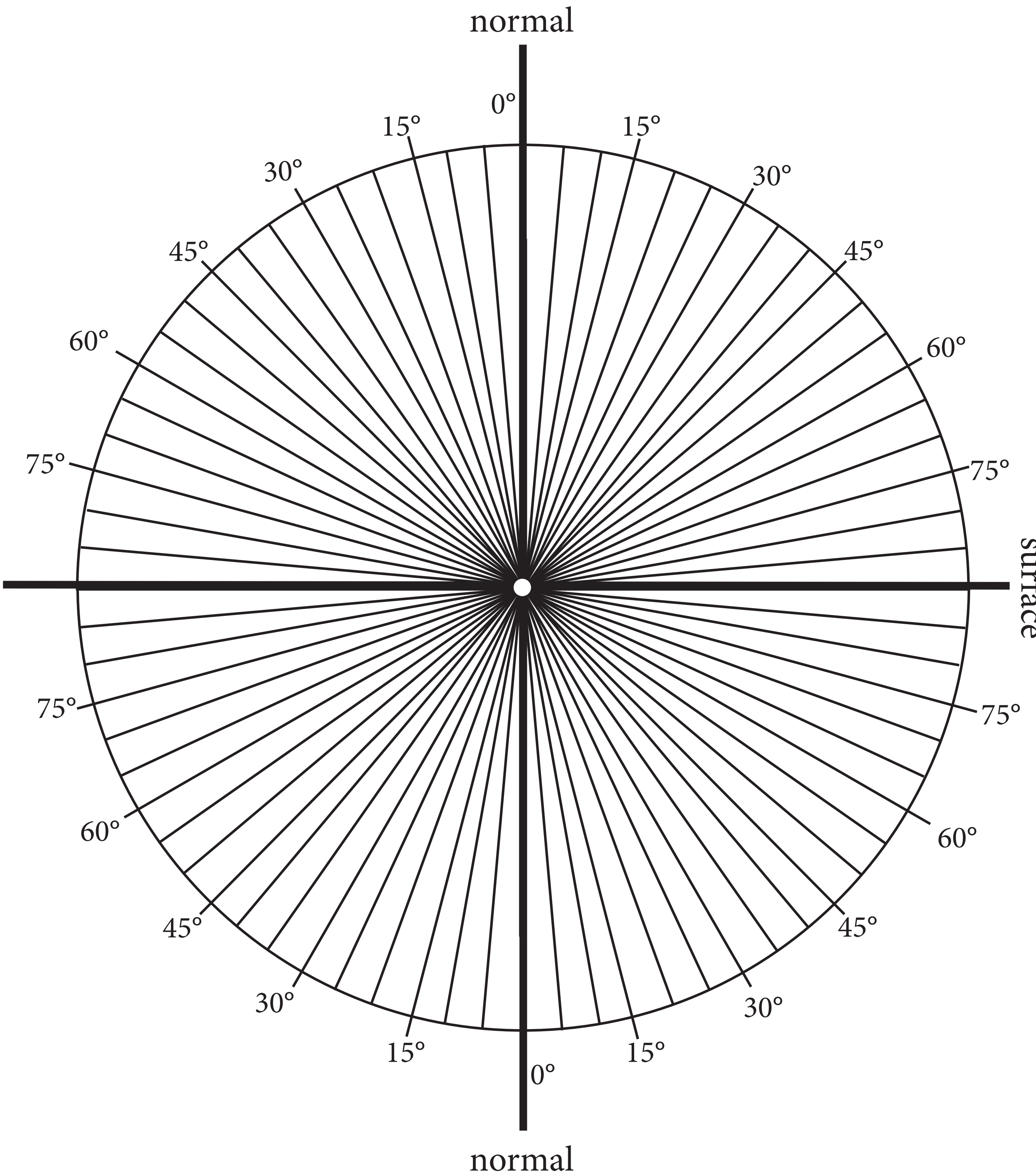
Name__________________________________ Date____________ Period _____

6.b. Paper Protractor



Name______________________________________ Date____________ Period ______

6.b. Paper Protractor (2/2)



LESSON 7

Plan/Build/Test

Lesson Objectives

Students will be able to:

- design a laser security system that incorporates their knowledge of reflection, refraction, absorption, and transmission of light.
- engage in evidence-based reasoning to select the design that best addresses the criteria and constraints of the design challenge.
- construct a model laser security system that meets the criteria and constraints defined by the client.
- provide constructive design feedback to their peers.
- identify ways to improve their initial security system designs.

Time Required

Two-three 50-minute class period

Materials

Per classroom:

- extra laser pointers
- hot glue gun and glue sticks
- EDP poster

Per team:

- 40 cm x 50 cm grid paper (one sheet per plan)
- (1) ruler or straightedge
- (1) protractor
- (1) laser pointer (ideally with a button/switch that keeps it turned on)
- (1) concave lens
- (1) convex lens
- (1) flat lens
- (3) flat mirrors
- (1) concave mirror
- (1) model person (on pencil)
- (6-10) large binder clips
- baby powder
- small brush (such as a makeup brush)
- Petri dish
- (7) index cards
- clay

Per student:

- (1) pencil
- engineering notebook
- EDP Slider

Lesson Summary

In this lesson, students apply their previous learning to make a plan for their laser security system. Students individually brainstorm potential design ideas, then work with their teammates to compare ideas and create at least two team plans using precise measurements from their previous labs. To decide between their team plans, students complete evidence-based reasoning graphics to examine their designs in relation to the criteria and constraints of the design challenge. Students make a physical prototype of their laser security system using the design plan they developed. They test their own security system, as well as other teams' designs, then provide feedback to the other teams. From their own observations and the feedback they receive from their peers, teams of students identify ways they can improve their security system design based on the client's criteria and constraints.

Background

Teacher Background

Evidence-based Reasoning: Evidence-based reasoning (EBR) refers to the engineering practice of providing rationale for design ideas and decisions. It is somewhat similar to scientific argumentation in the sense that it involves using evidence and explanations to support a statement, but it is ultimately different. In EBR, the statement being supported is an engineering design idea or decision, whereas in scientific argumentation it is a claim or conclusion about a natural phenomenon. EBR is used in the context of generating solutions for engineering problems; scientific argumentation is used to answer scientific questions about nature. Science and mathematical principles are important justifications for scientific argumentation and EBR. However, EBR often also includes justifications related to the context, criteria, and constraints of the engineering problem (e.g., cost, user needs, technical feasibility). In this lesson, students will use EBR to think deeply about their proposed design ideas and to justify them with information about the engineering problem and their science and mathematics knowledge.

This lesson is designed to cover 2-3 class periods and includes planning, building, and testing. Move through these phases at a rate appropriate for the students. At the start and end of each lesson, discuss where the students are in the EDP.

In this lesson, the word "sketch" is used to describe a rough drawing of a design and the word "plan" is used to described a detailed and precise drawing of a design. Individual students will make sketches to have a medium to brainstorm and show their ideas to their team.

Planning Options

There are two options for making the plan. Choose the one most appropriate for the class.

- **Option 1:** Have students make a real size drawing of their design using a sheet of 40 cm x 50 cm grid paper
- **Option 2:** Have students make a scale drawing of their plan.

Plan/Build/Test

Each team will have 1 laser pointer, 3 lenses (1 concave, 1 convex, and 1 flat), 3 flat mirrors, and 1 concave mirror for their prototype. These should be the same lenses and mirrors they used in lesson 6 to take their measurements.

Testing Options
There are three options for testing the prototype. Option 1 is used in the lesson plan, but choose the method most appropriate for the class.

- **Option 1:** Have students test their own designs with baby powder. Give students a small amount of baby powder (such as in a petri dish) and a small brush (such as a make-up brush) and have them sprinkle the baby powder near the laser beam in order to see it. To prevent messes, teams should only receive a small amount of baby powder. To help with cleanup, it might be helpful to cover each table with a large sheet of butcher paper or newspaper.
- **Option 2:** Use a fog machine. This could possibly set off the fire alarm, so it is recommended to be used outside. Maintain control of the fog machine, and when students are ready to test their designs, they will seek the teacher's help with the fog machine.
- **Option 3:** Use dry ice instead of a fog machine.

Before the Activity

- If using the real size plan option, obtain 40 cm x 50 cm grid paper (one sheet per team) to indicate the size of the "room" where the laser security system will be.
- If using the scale-size option, determine what scale students should use (can be differentiated based on team needs) and obtain any necessary materials for supporting students in their scale drawings.
- Glue a model person to the end of a pencil. This will allow students to test their security system designs by seeing whether the model person has to cross laser lines as it is pushed through the box.
- Make copies of duplication masters (1 per student).
- Make copies of the educator resources:
    - *7.f. Teacher Observation Protocol: Try Lesson* and *7.g. Teacher Observation Protocol: Test Lesson* (enough for each team to have a line on the sheet)
    - *7.i. Test Solution Ideas Notebook Prompt Rubric* (1 per student)

Classroom Instruction

Introduction

1. **Identify where they are in the engineering design process. (Plan)** Refer students to their EDP sliders. **Ask:** *Which phases of the engineering design process have we used so far? What do you think we will be doing next?*

2. **Review engineering problem, constraints, and criteria**. Refer students back to the client letters, problem scoping worksheet, and the notes they have taken throughout the unit. **Ask:** *What problem are we trying to solve with our designs? How will you know if your design is successful (criteria)? What constraints or limits will affect how you create your design?*

Standards Addressed

- Next Generation Science Standards: MS-PS4-1, MS-PS4-2, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4
- Common Core State Standards – Mathematics: 4.MD.C.5, 4.MD.C.6, 7.G.A.1, 7.G.A.2, 8.G.A.1, 8.G.A.1.B, 8.G.A.5, 6.SP.A.2, 6.SP.B.5, 6.SP.B.5.A

Key Terms

evidence-based reasoning, simplifying assumptions, criteria, constraints, sketch, plan, prototype

Assessments

Pre-Activity Assessment
Assess students' understanding of the engineering design context based on their responses to the following questions: *What problem are we trying to solve with our designs? How will you know if your design is successful (criteria)? What constraints or limits will affect how you create your design?* Check students' understanding and use of evidence-based reasoning based on their responses to the question *What were some of the things you considered in selecting the best plan for your security system?*

Activity Embedded Assessment
Examine students' individual sketches and team security system design plans for labels connecting the design to their knowledge of reflection and refraction of light. Observe students as they build their security system prototypes, looking for connections between the science content learned throughout the unit and their designs. Use the *7.f. Teacher Observation Protocol: Try Lesson* and the *7.g. Teacher Observation Protocol: Test Lesson* to assess student work.

LESSON 7 Plan/Build/Test

Post-Activity Assessment
Check student understanding of the engineering design challenge and their use of data to make decisions using their evidence-based reasoning graphics. Provide feedback to students using the *7.d. Evidence-Based Reasoning Rubric* and the *7.b. Planning Reflection Questions Rubric.* Read students' responses on the *7.h. Test Solution Ideas* worksheet, looking for a critical evaluation of their design and ideas for improvement on later iterations. Use the *7.i. Test Solution Ideas Notebook Prompt Rubric* to provide feedback.

DUPLICATION MASTERS

- 7.a. Planning Reflection Questions
- 7.c. Evidence-Based Reasoning
- 7.h. Test Solution Ideas

EDUCATOR RESOURCES

- 7.b. Planning Reflection Questions Rubric
- 7.d. Evidence-Based Reasoning Rubric
- 7.e. Evidence Based Reasoning Instructions
- 7.f. Teacher Observation Protocol: Try Lesson
- 7.g. Teacher Observation Protocol: Test Lesson
- 7.i. Test Solution Ideas Notebook Prompt Rubric

Activity

3. **Generate ideas individually.** Explain to students that they will be taking the next step in the engineering design process, making a plan for their laser security system designs. Explain that idea generation is an important part of the engineering design process. **Say:** *The goal of idea generating is to develop many different ideas so you have many to choose from. Not all of the ideas will be perfect, but you will be able to combine and adapt your ideas with your teammates' ideas to develop a team design that meets the criteria and constraints the client put forth.* Explain that students will work on their own to create sketches of how their laser security system could be designed. Their team plans will need to be exact and include measurements. The individual sketches will not be exact, but they should include the source of light, any objects that will change the way the light is traveling, the path the light will take throughout the room, and the artifacts they are protecting. Students will be able to choose the location of the artifact or artifacts within the room. Remind students that they must protect at least one artifact, but they may choose to protect more than one if they desire. Give students time to sketch their individual ideas in their engineering notebooks. Remind students that it is good to have more than one idea so that when they meet with their teams they will have a lot of ideas to choose from.

4. **Determine the pros and cons of their solutions.** Pass out the *7.a. Planning Reflection Questions* to each student and have them answer question 1 about the pros and cons of each of their solutions.

5. **Plan and build as a team.** Direct students to share their brainstormed ideas with their teammates. Give each team member an opportunity to share the ideas developed individually. This can be monitored by the teacher to keep track of a certain amount of time for each student to talk or tracked by student teams. **Say:** *Each team will be developing one design plan for your laser security system. You have a lot of ideas from your individual brainstorms, and, as a team, you need to start to think about which aspects of each person's plan to include in your team design.* Remind students that the team plan should be more detailed and precise than their individual sketches. They will need to use protractors and straightedges in their plan. As students create their team plans, they may use mirrors, lenses, binder clips, and any other supplies they will use in their designs **except** laser pointers.Detailed plans will make building the security system easier, so in addition to the source of light, any objects that will change the way the light is traveling, the path the light will take throughout the room, and the artifacts they are protecting, students should also label all the angles in their plan. They will need to use their data from their experiments to know what the angles of reflection and refraction should be. As students work to build their prototype security systems, circulate around the classroom, ensuring that students are sharing in the building and including their teammates. Utilize the *7.f. Teacher Observation Protocol: Try Lesson* to assess student work.

6. **Introduce evidence-based reasoning. Say:** *Scientists and engineers work hard to use evidence to make decisions, so you're going to fill out an evidence-based reasoning graphic to justify your design decision.* Post a *7.c. Evidence-Based Reasoning* graphic on the board or on a piece of poster paper. **Say:** *You will need to support your design ideas with evidence and explanations. We will discuss each of the parts together.* Clarify with students that the Evidence-Based Reasoning poster will have general explanations and reminders of what kind of information should go in each section. This is different from what the students will write in the templates. They will fill out the boxes with information specific to their engineering design problem.

7. **Review the engineering problem.** Direct students' attention to the "Problem including Criteria and Constraints" section of the EBR graphic. On the poster, write down a general definition of the term problem: the engineering problem the client asked you to solve. Instruct students to write a summary of their engineering problem in this section, leaving room for criteria and constraints.

8. **Review the criteria and constraints of the problem. Ask:** *Can anyone remind me what the words "criteria" and "constraints" mean?* Criteria are the requirements, or goals, of the designed solutions. Constraints are things that limit design possibilities. Write these definitions on the EBR poster. Refer students back to their lists of criteria and constraints from their "Define the Problem" notes. **Ask:** *What are some of the criteria and constraints of our engineering problem?* Discuss the criteria and constraints of the problem, and have students write them in the "Problem including Criteria and Constraints" section of the EBR graphic. Remind students that they have created a team plan for their laser security system in the previous lesson. **Ask:** *What were some of the things you considered in selecting the best plan for your security system?* Explain that today's goals are to build their security system according to their plan, test their own and others' designs, and reflect on any changes they would like to make to their design. Remind students that the security system is inside a room that has walls, so any materials that are part of their design must be contained within the area of the paper they used for their plan.

9. **Introduce the concept of simplifying assumptions. Say:** *Engineers usually don't deal with every single aspect of a problem at once because that makes the problem too difficult to solve. Instead, they make a complex problem simpler, sometimes by ignoring some of the details of the problem and sometimes by pretending certain things are true about the problem when they actually aren't*. Write "ways to make a complex problem simpler" in the "Simplifying Assumptions (if any)" section of the Evidence-Based Reasoning poster. **Ask:** *What are some parts of our engineering problem that we can make simpler?* This may be a difficult concept for students, so provide an example or two if students struggle.
   - Simplifying assumptions (things to ignore): aesthetics/appearance, durability (how well it withstands wear and damage).
   - Simplifying assumptions (assume certain things are true when they

aren't): materials used in classroom are similar to those the client has.

10. **Explain what information goes in each of the remaining sections.** Have students guess what kind of information they think should go in the "Design Idea," "Data/Evidence," and "Justification" sections of the EBR graphic. Write down relevant student suggestions in the appropriate section of the EBR poster. This could include:
    - **Design Idea:** description of the design idea; drawings of the design idea, possibly with different views (e.g., top view, side view); dimensions/sizes/angles; materials in the design idea labeled to show where they are used; interesting features of the design idea.
    - **Data/Evidence:** Observations and data that show why you think your design will work. Examples: data from the labs and simulations.
    - **Justification:** Complete sentences that state why you think your design will be successful. These sentences should refer to the problem, criteria, constraints, idea, and data/evidence.

11. **Complete the EBR graphic as a team.** Provide students with time to complete the *7.c. Evidence-Based Reasoning* with their teammates.

12. Have students answer question 2 on *7.a. Planning Reflection Questions* about their team plan. Make sure students have access to straightedges and protractors, then give students time to create a team design plan. As students work in their teams, utilize the teacher observation protocol to assess student work. While planning, students may use their mirrors and lenses to help with the plan, but should not have their laser pointers at this point. NOTE: If teams finish quickly, encourage them to double-check the measurements on their plan and ensure that everything is accurate. If time allows, direct these teams to create an additional design plan that includes an additional constraint. For example, the team could choose to protect more than one artifact, include a wall or display in the middle of the room, or include extra instances of reflection and refraction.

13. **Review safety.** Remind students that they need to use the mirrors and lasers safely and responsibly, which includes never shining the light at someone's face.

14. **Test the security system.** As students finish building their prototypes, give them the baby powder and brush to test their prototype. Direct one of the students to push the model person through the security system, counting the number of laser lines the person has to cross to get to the artifacts. If students make changes to their plan, have them keep a list in their notebooks of changes they make. Additionally, students should mark these changes on their grid paper with their plan in a different color so that they can see the changes. Limit students to 2 small changes in their design, such as adjusting a mirorr. Other changes should be made in the redesign. Utilize the *7.g. Teacher Observation Protocol: Test Lesson* to assess student work.

15. **Conduct a security system gallery walk.** Once all teams have finished testing their prototypes, explain that the students, like engineers, are going to learn from other teams' designs. Tell students they will have the opportunity to look at and test each team's prototype to get ideas and leave feedback for the team. At each prototype, they will test the design, then leave an index card with a question and a star from their team. The question can be about something they think the team should consider trying or something they would like to know about the design. The star should be a compliment about some aspect of the team's design. Distribute index cards to each team and direct students to the first design they will review. Remind students that they must be careful not to change another team's design and that they should travel with their teammates. NOTE: Decide how much structure to provide students. If desired, turn off the lights for a designated amount of time to allow for testing, and when the lights are turned on, that is the students' cue to start writing on their index cards. Then, instruct the students to rotate to the next prototype and repeat the process until they have finished testing all other teams' designs or time runs out. Students will need to take their baby powder and brushes with them as they move around the classroom, so remind them to move carefully.

16. **Reflect on prototypes.** After students have tested other teams' prototypes, direct them to return to their own prototype work station. Direct students to read the index cards left behind by their peers and complete *7.h. Test Solution Ideas* individually. These questions are intended to help students think about what the results of their test tell them and how they can modify their designs for improvement. Students' ideas can come from the index card suggestions or their own observations. After students have responded to the questions individually, instruct them to confer with their teammates and add a team response.

Closure

17. **Connect to EDP.** Refer students to their EDP sliders. **Ask:** *Which phases of the engineering design process did we use today? How do you know you used those phases? What should we do next?* Explain that students will have an opportunity to improve their prototypes based on what they learned in this lesson. Remind them that they are trying to develop the best solution to the client's problem, and, as is the case for professional engineers, the first idea or design is rarely the best.

LESSON 7

Name________________________________ Date___________ Period _____

7.a. Planning Reflection Questions

Directions: Please answer the following questions as directed.

1. What are the pros and cons of each of your own solution ideas?

2. Which solution did your team choose and why? Provide evidence for your reason.

Student Name_______________________________ Date___________ Period _____

7.b. Planning Reflection Questions Rubric

Problem	Question	Learning Objectives	Rubric	
7.a.1	What are the pros and cons of each of your own solution ideas?	Select potential solution through systematic evaluation of various solutions based on the problem.	yes no	**Provided at least 1 pro for each solution generated (as an individual)**
			yes no	**Provided at least 1 con for each solution generated (as an individual)**
7.a.2	Which solution did your team choose and why? Provide evidence for your reason.	Select potential solution through systematic evaluation of various solutions based on the problem.	yes no	**Stated which solution was chosen**
			yes no	**Provided an explanation for why the team chose that solution that was based on evidence**

Notes:

LESSON 7

Name______________________________ Date__________ Period _____

7.c. Evidence-Based Reasoning (1/2)

Problem with Criteria & Constraints • Explain the client's problem that needs a solution and why it is important to solve. • List criteria and constraints you will use to decide if your solution is working.	
Problem: **Criteria:** **Constraints:**	
Simplifying Assumptions • List things that might be important but you have decided not to worry about.	
Design Idea #____ • Plan including drawing, labels of materials used, and labels of what each part does.	**Data/Evidence** • List science/mathematics learned and/or results of tests that support your design idea.

Name____________________________________ Date____________ Period _____

7.c. Evidence-Based Reasoning (2/2)

Justification - Why do you think this design idea will work? • Explain how your data and evidence support your design idea in order to meet criteria/constraints.

Student Name______________________ Date__________ Period _____

7.d. Evidence-Based Reasoning Rubric

Section	Learning Objective	Rubric	
Problem	Explain the problem based on a synthesis of information. Explain why the problem is important to solve based on evidence that is relevant to the problem.	yes no	**Identified problem**
		yes no	**Explained why the problem is important**
Criteria	Explain criteria based on given information.	yes no	**Identified at least 1 criterion**
Constraints	Explain constraints based on information.	yes no	**Identified at least 1 constraint**
Simplifying Assumptions	Explain assumptions they have made in order to make solving the problem more manageable.	yes no	**Identified at least 1 simplifying assumption**
Design Idea	Communicate design idea through drawing, including labels for materials and function of parts.	yes no	**Included drawing to represent design idea**
		yes no	**Included labels of materials**
		yes no	**Included labels of what each part does**
Data/Evidence (List math/science learned and/or results of tests that support your design idea)	Apply evidence gathered from testing to choose solution. Apply math/science concepts to choose solution.	yes no	**Listed at least 1 piece of valid evidence**
		yes no	**Evidence is from mathematics/science they have learned or from the results of the tests**
Justification (Explain how your data/evidence supports your design idea in order to meet criteria/constraints. Why do you think this will work?)	Justify why their design solution is appropriate based on application of core science/ mathematics concepts Justify why their design solution is appropriate based on information obtained in problem scoping.	yes no	**Included explanation of how their data/ evidence supports their design idea**
		yes no	**Explained why this will work**
		yes no	**Explained how design idea will meet criteria/constraints**
Notes:			

7.e. Evidence-Based Reasoning Instructions

Poster with Explanation

Problem with Criteria & Constraints
- Explain the client's problem that needs a solution and why it is important to solve.
- List criteria and constraints you will use to decide if your solution is working.

Problem: **the engineering problem the client asked you to solve**

Criteria: **the requirements, or goals, of the designed solutions**

Constraints: **things that limit design possibilities**

Simplifying Assumptions
- List things that might be important but you have decided not to worry about.

Ways to make a complex problem simpler

Design Idea #____ • Plan including drawing, labels of materials used, and labels of what each part does.	**Data/Evidence** • List science/mathematics learned and/or results of tests that support your design idea.
• **Drawings of the design, different views** • **Dimensions (sizes)** • **Description of the design - labels of how different parts function** • **Label materials in design (show where they are used)** • **Interesting features**	**Observations and data that show why you think your design will work** **Examples:** • **Data from science and mathematics lessons, labs, and activities** • **Theoretical science/mathematics that provide reasons for choices they made** • **Total cost of design**

Justification - Why do you think this design idea will work?
- Explain how your data and evidence support your design idea in order to meet criteria/constraints.

Complete sentences that state why it is possible that the design will be successful. These sentences should refer to the problem, criteria, constraints, idea, and data/evidence.

7.e. Evidence-Based Reasoning Instructions

Laser Security System Example

Problem with Criteria & Constraints • Explain the client's problem that needs a solution and why it is important to solve. • List criteria and constraints you will use to decide if your solution is working.	
Problem: **The current security system has not protected the artifacts in a museum. The client needs to protect artifacts in a traveling museum from theft with a laser security system.** **Criteria:** **The laser beam needs to cross at least 3 times between the door and each artifact. The light needs to reflect and refract at least once. At least 1 artifact must be displayed.** **Constraints:** **The prototype must fit within 40 cm x 50 cm. We are limited to 3 flat mirrors, 3 lenses, & 1 concave mirror. We have 1 laser pointer.**	
Simplifying Assumptions • List things that might be important but you have decided not to worry about.	
We do not need to worry about aesthetics/appearance, durability of the materials, or scaling the security system up to the correct size for the museum display. We will assume that the materials available for our use in the classroom are similar to the materials the client will be using for the final security system design.	
Design Idea #____ • Plan including drawing, labels of materials used, and labels of what each part does.	**Data/Evidence** • List science/mathematics learned and/or results of tests that support your design idea.
• **Student plans will vary. See EBR poster for the type of information students should include in their plan.**	• **Student responses will vary. See EBR poster for the type of information students should include in their data/ evidence.**
Justification - Why do you think this design idea will work? • Explain how your data and evidence support your design idea in order to meet criteria/constraints.	
Student responses will vary. See EBR poster for the type of information students should include in their explanation.	

7.f. Teacher Observation Protocol: Try Lesson

Team #	All team members members are on-task to make/try their solution.	One or more team members are not on-task.	Team has made appropriate progress on their solution.	Team is struggling to make their solution.	Team is making/made a solution directly related to problem.	Team is making/made a something unrelated to problem.	Notes

Optional Question Prompts:

NOTE: These questions can be used to further draw out and scaffold students' evidence-based reasoning. While the main purpose of these questions is to assess students' reasoning, it is also appropriate to interact with students/question for the purpose to support learning.

1. Can you tell me about your solution? What are you designing?
2. What were some of the other solution ideas you generated? How well did they address the problem?
3. How did you decide to move forward with this idea? What evidence do you have that your design will solve the problem for the client?

7.g. Teacher Observation Protocol: Test Lesson

Team #	All team members are on-task to test solution.	One or more team members are not on-task.	Team has made appropriate progress on testing and analysis.	Team is struggling to test or analyze their solution.	Team has identified how to improve solution.	Team is struggling to consider improved performance.	Notes

Optional Question Prompts:

NOTE: These questions can be used to further draw out and scaffold students' evidence-based reasoning. While the main purpose of these questions is to assess students' reasoning, it is also appropriate to interact with students/question for the purpose to support learning.

1. What did you find out from testing?
2. How did you interpret the findings from your tests? What do you think the results mean?
3. How did you decide what could improve your solution's performance?

Name________________________________ Date___________ Period _____

7.h. Test Solution Ideas (1/2)

Section 1

Directions: Please answer the following questions about what you learned from testing.

1. What were the results of your test(s)?

2. What have you learned about the performance of your solution from your test results? Explain both the things that worked and did not work.

   My response:

   Team response:

3. What changes will you make to your solution based on the results of your tests?

   My response:

   Team response:

4. Why will you make those changes? Think about the results of your test and the science and mathematics you have learned.

   My response:

   Team response:

Name________________________________ Date___________ Period _____

7.h. Test Solution Ideas (2/2)

Section 2

Directions: Please answer the following questions about the overall quality of your solution.

5. In what ways does your solution meet the criteria and constraints of the problem?

   My response:

   Team response:

6. In what ways does your solution not yet meet the criteria and constraints of the problem?

   My response:

   Team response:

Student Name________________________________ Date____________ Period _____

7.i. Test Solution Ideas Rubric

Problem	Question	Learning Objectives	Rubric	
7.h.1	What were the results of your test(s)?	Analyze test results.	yes no	**Listed specific results of tests**
7.h.2-4	2. What have you learned about the performance of your solution from your test results? Explain both the things that worked and did not work.	Analyze test results.	yes no	**Explained advantages of solution found in tests**
			yes no	**Explained drawbacks of solution found in tests**
	3, What changes will you make to your solution based on the results of your tests?	Apply evidence gathered through test analysis to improve the performance of chosen solution.	yes no	**Listed planned improvements**
	4. Why will you make those changes? Think about the results of your tests and the mathematics and science you have learned.	Apply evidence gathered from testing to choose solution.	yes no	**Explained rationale for improvements based on test results**
		Apply mathematics/science concepts to inform redesign.	yes no	**Explained rationale for improvements based on correct understanding of mathematics/ science**
7.h.5	In what ways does your solution meet criteria and constraints of the problem?	Evaluate the alignment between their proposed solution and the problem.	yes no	**Compared their solution to specified criteria and constraints**
7.h.6	In what ways does your solution not yet meet the criteria and constraints of the problem?	Evaluate the alignment between their proposed solution and the problem.	yes no	**Contrasted their solution to specified criteria and constraints**

Notes:

LESSON 8

Redesign

Lesson Objectives

Students will be able to:

- design a laser security system that incorporates their knowledge of reflection, refraction, absorption, and transmission of light.
- use peer feedback and their own observations to improve their design.
- construct a model laser security system that meets the criteria and constraints defined by the client.
- use evidence to justify whether their design meets the client's criteria and constraints.

Time Required

One-two 50-minute class periods

Materials

Per classroom:

- extra laser pointers
- EDP poster

Per team:

- 40 x 50 cm grid paper (one sheet per plan)
- (1) ruler or straightedge
- (1) protractor
- (1) laser pointer (ideally with a button/switch that keeps it turned on)
- (1) concave lens
- (1) convex lens
- (1) flat lens
- (3) flat mirrors
- (1) concave mirror
- (1) model person (on a pencil)
- large binder clips
- baby powder
- Petri dish
- small brush (such as a makeup brush)
- clay

Per student:

- (1) pencil
- engineering notebook
- EDP poster

Key Terms

criteria, constraints, prototype,

Lesson Summary

In this lesson, students utilize their reflections from the previous lesson to improve their laser security system prototypes. They work as a team to create a new design plan, then build, test, and evaluate their prototype. Students compose letters to the client to justify why their design fulfills the criteria and constraints. They also reflect on how their understanding of the design challenge has evolved throughout the course of the unit.

Background

Before the Activity

Learning from failure: One of the most important aspects of engineering is learning from failure. Engineers often purposefully test models and prototypes until failure in order to better understand the limits of their designs. The engineers then use what they learned from this failure to redesign. Thus, in the engineering design process, it is important to continue beyond the first design cycle.

Redesign: After analyzing and evaluating their first prototype, students will begin to identify potential problems in the design, construction, organization, or cost of the original. At this point, some students will want to leap into a new design, others will insist on the success of their first prototype, while others may want to give up. The teacher can be a key factor in encouraging and guiding students through this transitional time. Because some students may be overly eager and want to skip the plan step of redesign, remind them of the importance of thinking through a design and creating written plans. For teams who are satisfied with their initial design's performance, encourage them to create a design that improves performance. For all teams, especially those who may want to give up, remind them that failing and then redesign is a key part of engineering and what professional engineers do. This is the stage in which students' understanding and skills are deepened and strengthened as they struggle with challenges and decisions. Learning from failure is not just an important skill for engineering, but it is also an important life skill. For redesign, encourage student teams that did not meet the main criteria to focus on meeting those criteria in their redesign. For teams that did meet the main criteria, encourage them to improve their design. Additionally, teams can think about other features that came up during defining the problem or testing the solution.

In this lesson, students will be generating a list of requirements to describe what makes a good letter to the client. The purpose of this letter is for students to articulate the design problem and justify the solution they developed in an attempt to convince the client their security system design should be selected. Before brainstorming ideas with the students, it will be helpful if the teacher has an idea of what should be included in the letters so that students can be prompted to think of additional components or their ideas supplemented with teacher contributions.

Print and make copies of the following worksheets in the labeled amounts:

- *8.a. Redesign Evaluation* (1 per student)
- *8.d. Criteria and Constraints Assessment Checklist* (1 per team)

- *8.e. Unit Reflection* (1 per student)
- *8.f. Teacher Observation Protocol: Redesign Lesson* (enough for each team to have a line on the sheet).

Classroom Instruction

Introduction

1. **Discuss redesign.** Remind students that they had a chance to build their laser security system, then test their own design and other teams' designs. **Ask:** *What are some things you might want to change about your initial designs? How will those changes help your design meet the client's criteria more effectively, while considering the design constraints?* Explain that they will have an opportunity to redesign their system to improve upon the first design.

2. **Identify where they are in the engineering design process. (Decide)** Refer students to their EDP sliders. **Ask:** *Which phases of the engineering design process will we use today? How do you know?*

Activity

3. **Review safety.** Remind students that they need to use the mirrors and lasers safely and responsibly, which includes never shining the light at someone's face.

4. **Plan the redesign.** Direct students to their responses to the Section 1 and Section 2 questions on the *7.h. Test Solution Ideas* worksheet from the previous lesson. Explain that, as a team, they need to use this information to make a new plan for their security system. Tell students they will spend a couple of minutes formulating ideas individually to determine what they think needs to be changed about their system. They should record their individual ideas for what needs to be changed and why that should be changed in their engineering notebooks. After several minutes, teams will come together and share their individual ideas, working to form a team plan. Remind students that they can sketch their individual ideas in their engineering notebook, but their team plan should be detailed and precise, including labeled angles based on experimental data. Make sure students have access to straightedges, protractors, and 40 cm x 50 cm grid paper.

5. **Build the redesigned prototype.** As students finish their plans, give them time to get the needed materials and arrange them on their paper plan sheet. As students work to build their prototype security systems, circulate around the classroom, ensuring that students are sharing in the design work and including their teammates. Use the teacher observation protocol to assess student work.

6. **Test redesigned security system.** As students finish building their prototypes, give each team baby powder and brushes to test their design. Direct one of the students to push the model person through the security system, counting the number of laser lines the person has to cross to get to the artifacts. Have students complete the *8.a. Redesign Evaluation* worksheet.

evidence-based reasoning

Standards Addressed

- Next Generation Science Standards: MS-ETS1-2, MS-ETS1-3, MS-ETS1-4
- Common Core State Standards – Mathematics: 4.MD.C.5, 4.MD.C.6, 7.G.A.1, 8.G.A.1, 8.G.A.1.B, 8.G.A.5

Assessments

Pre-Activity Assessment
Check students' understanding of the criteria and constraints of the challenge based on their responses to the questions in the introduction.

Activity Embedded Assessment
In students' client letters, look for sufficient detail related to the class-constructed list of elements for the letter. Examine students' *8.a. Redesign Evaluation* worksheets for details of how their redesigned solution meets the criteria and constraints. Use the *8.c. Teacher Observation Protocol: Redesign Lesson* to assess student work. Assess student work with the *8.b. Redesign Evaluation Rubric*

Post-Activity Assessment
Read students' *8.e. Unit Reflection* worksheets and assess their understanding of the engineering design process using the *9.d. Unit Reflection Rubric*. Assess students' final designs based on the *9.d. Criteria and Constraints Assessment Checklist*.

DUPLICATION MASTERS

- 8.a. Redesign Evaluation
- 8.e. Unit Reflection

EDUCATOR RESOURCES

- 8.b. Redesign Evaluation Rubric
- 8.c. Teacher Observation Protocol: Redesign Lesson
- 8.d. Criteria and Constraints Assessment Checklist
- 8.f. Unit Reflection Rubric

Redesign

7. **Assess student progress.** As students are testing and evaluating their redesigned security system, walk around and assess student progress with *8.c. Teacher Observation Protocol: Redesign Lesson*.

8. **Communicate to the client.** Explain that students are going to report their final designs to the client using a letter. They will be trying to convince the client that their solution is the best, and they should refer to the EBR Poster to help them justify their choices. **Ask:** *What do you think should be included in communication to the client?* Record student ideas on the board or a piece of poster paper; this will provide students with guidelines or a checklist for their writing. Refer students to the EBR poster as needed to have them identify components of EBR as parts of a good letter. Provide students with time to write or type their letters in their teams. Use the *8.d. Criteria and Constraints Assessment Checklist* to evaluate students' final designs based on their letters. **(Optional)** Have teams give a presentation to the class or create a video to communicate their design to the client.

Closure

9. **Reflect on the unit. Ask:** *How was your work in this unit similar to the work of professional engineers?* Remind students that they spent this unit working through the engineering design process, which is similar to what real engineers do in their real-world jobs. Tell them that their understanding of the client's problem and how to design a solution has likely changed over the course of the unit, and they should capture those changes in their thinking by filling out the questions in the *8.e. Unit Reflection*.

LESSON 8

Name________________________________ Date___________ Period _____

8.a. Redesign Evaluation

Directions: Please answer the following questions about the overall quality of your solution.

1. What are the results of your test(s)?
   My response:

   Team response:

2. Did your redesign improve your solution? Why or why not?
   My response:

   Team response:

3. If you could do another redesign, how would you try to improve your solution?
   My response:

   Team response:

LESSON 8

Student Name________________________ Date____________ Period _____

8.b. Redesign Evaluation Rubric

Problem	Question	Learning Objectives	Rubric	
8.a.1	What were the results of your test(s)?	Test improved solution and reflect on test results.	yes no	**Listed specific results of tests**
8.a.2	Did your redesign improve your solution? Why or why not?	Test improved solution and reflect on test results.	yes no	**Answered question and provided reasons for improvement or no improvement.**
8.a.3	If you could do another redesign, how would you try to improve your solution?	Test improved solution and reflect on test results.	yes no	**Listed planned improvements**

Notes:

8.c. Teacher Observation Protocol: Redesign Lesson

Team #	All team members are on-task to retest their solution.	One or more team members are not on-task.	Team has attempted to improve the performance of their solution.	Unclear what has been done to improve their solution.	Notes

Optional Question Prompts:

NOTE: These questions can be used to further draw out and scaffold students' evidence-based reasoning. While the main purpose of these questions is to assess students' reasoning, it is also appropriate to interact with students/question for the purpose to support learning.

1. Can you tell me about how you are working to improve your solution?
2. What were some of the other solution improvement ideas you generated?
3. How did you decide to move forward with this idea? What evidence do you have that your improved design will solve the problem for the client?

8.d. Criteria and Constraints Assessment Checklist

Criteria and Constraints:

- ☐ Laser beam crosses at least three times between the door and each artifact
- ☐ Light reflects at least one time
- ☐ Light refracts at least one time
- ☐ Angles are labeled in plan
- ☐ Prototype fits within the 40 cm x 50 cm grid paper
- ☐ At least one artifact is featured within the room
- ☐ Design uses only one laser pointer
- ☐ Design uses a maximum of three flat mirrors
- ☐ Design uses a maximum of three lenses
- ☐ Design uses a maximum of one concave mirror

LESSON 8

Name________________________________ Date___________ Period _____

8.e. Unit Reflection

Directions: First, **on your own**, answer each of the following questions beside the "My Response" space. Then, in your teams, each person is to share their response and discuss. In the space "Team Response," **write your revised answer to the question**, based on discussion with your team. You may use a different color writing utensil to distinguish your answer and how it changed after talking with teammates.

1. **How has your <u>understanding of the problem</u> changed during the design process?**
   - Look back to the places where you defined the problem in your engineering notebook.
   - Think about client needs, criteria/constraints, and science/mathematics needed to solve the problem.

   My response:

   Team response:

2. **How has your <u>understanding of how to design a solution</u> changed during the design process?**
   - Look back in your engineering notebook to see how you developed your solution throughout solving the problem.
   - Think about what you did and how you made decisions to solve the problem.

   My response:

   Team response:

LESSON 8

Student Name________________________________ Date____________ Period _____

8.f. Unit Reflection Rubric

Problem	Question	Learning Objectives	Rubric	
8.e.1	How has your understanding of the problem changed during the design process? • Look back to the places where you defined the problem in your engineering notebook. • Think about client needs, criteria/constraints, and science/mathematics needed to solve the problem.	Communicate how their understanding of the problem deepened through the design process.	yes no	**Explained how their understanding of the problem has changed**
			yes no	**Included at least 1 of client needs, criteria/constraints, and science/mathematics in their explanation**
8.e.2	How has your understanding of how to design a solution changed during the design process? • Look back in your engineering notebook to see how you developed your solution throughout solving the problem. • Think about what you did and how you made decisions to solve the problem.	Communicate how their understanding of how to design solutions changed through the design process.	yes no	**Explained how their understanding of the how to design a solution has changed**
			yes no	**Included at least 1 example from their experience or how they made decisions in their explanation**

Notes:

LESSON 9

Summative Assessment

Lesson Objectives

Students will be able to:

- explain how they utilized the engineering design process within the context of the design challenge.
- identify the amplitude and wavelength of waves.
- explain why the light emitted by a flashlight appears different from the light emitted by a laser pointer.
- explain the difference between absorption and transmission.
- apply the law of reflection to predict the angle of reflection when given an angle of incidence.
- explain the difference between reflection and refraction.

Time Required

One-two 50 minute class periods

Materials

Per classroom:

- EDP poster

Per student:

- (1) protractor
- (1) pencil
- engineering notebook
- EDP slider

Standards Addressed

- Next Generation Science Standards: MS-PS4-1, MS-PS4-2
- Common Core State Standards – Mathematics: 4.MD.C.5, 4.MD.C.6, 7.G.A.2

Key Terms

engineering design process, amplitude, wavelength, color spectrum, absorption, transmission, reflection, refraction, angle of incidence, angle of reflection

Lesson Summary

In this lesson, students review their learning throughout the unit by revisiting their engineering notebooks and identifying the learning that was most integral to the design challenge. After they have had a chance to talk to their teammates about what they have learned, students complete a summative assessment to demonstrate their learning.

Background

Teacher Background

This lesson is intended as a summative assessment of students' learning throughout the unit. A review of the unit's concepts is included in the first portion of the activity, but this is optional.

Before the Activity

Make copies of the duplication masters (1 per student).

Classroom Instruction

Introduction

1. **Ask what students have learned.** Remind students that they have had opportunities to learn about light and how it travels over the course of this unit, and they have also applied their understanding to a real-world situation by designing a laser security system. **Ask:** *What is one big thing you learned in this unit?* Accept several student answers before moving into the review activity.

Activity

2. **Review what students have learned.** Explain that students are going to review what they learned by taking a tour through their engineering notebooks with their teammates. For each of the prompts on the *10.a. Unit Review* worksheet, they should look back at their experiment results and notes to write down at least one big idea they learned from that activity. Distribute copies of the *9.a. Unit Review* worksheet and explain that although students will fill out their own copy of the worksheet, they should discuss their answers with their teammates.

3. **Share ideas from review.** After students have had time to record at least one idea for each prompt on the duplication master, have students share ideas with the whole class. Record these ideas on the board, on poster paper, or on a copy of the worksheet using a document camera. When accurate ideas are shared, confirm that students have correctly described what was shown in the experiment. If inaccurate ideas are shared, ask questions of the team to try to get them to identify the problem with the idea. Based on student responses and your own additional input, clarify the misconception. Make sure to correct the given statement and have students write a revised version on their worksheet.

4. **Summative assessment.** Explain that students are going to demonstrate their learning in a summative assessment. This activity should be completed individually with no talking amongst teams. Distribute copies of *9.b. Summative Assessment* and give students with time to complete it.

Summative Assessment

Closure

5. **Review the EDP.** Remind students that the engineering design process is something that is useful for solving many different real-world problems and that the unit they just completed provided an opportunity for them to experience something engineers might do.

Assessments

Pre-Activity Assessment
Check student learning based on their responses to the question: *What is one big thing you learned in this unit?*

Activity Embedded Assessment
Read students' responses in their review tables, looking for scientifically accurate and thorough responses.

Post-Activity Assessment
Assess students' understanding of the unit's concepts using the *9.b. Summative Assessment.*

DUPLICATION MASTERS

- 9.a. Unit Review
- 9.b. Summative Assessment

EDUCATOR RESOURCES

- 9.c. Summative Assessment Answer Key

LESSON 9

Name________________________________ Date____________ Period _____

9.a. Unit Review

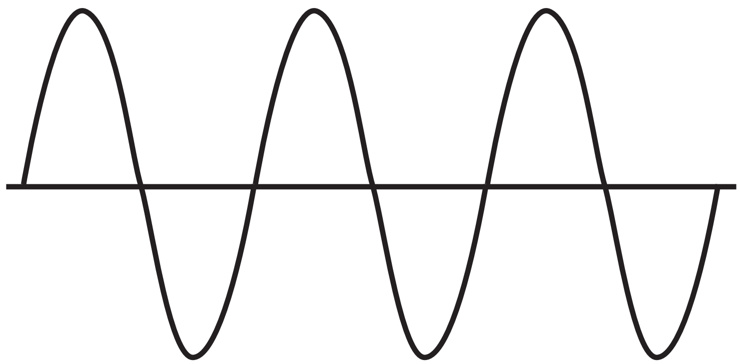
Topic	What we learned
engineering design process (EDP)	
light as a wave	
color spectrum	
how light travels	
reflection and refraction	
absorption and transmission	
light and mirrors	
light and lenses	
angle of incidence and angle of reflection	

LESSON 9

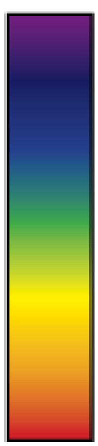
Name______________________________ Date__________ Period _____

9.b. Summative Assessment (1/4)

1. **Label the amplitude and wavelength of the wave shown below.**



2. **Fill in the table below with information about the color spectrum.**

Color	**Energy Levels** (Label the lowest and highest)	**Frequency** (Label the lowest and highest)	**Wavelength** (Label the shortest and longest)
Ultraviolet			
			
Infrared			

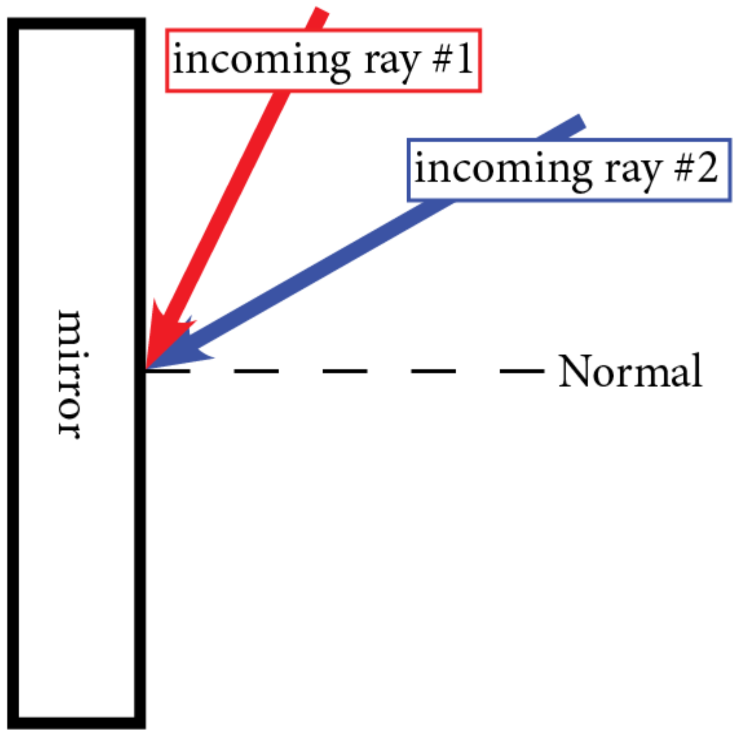
3. **Why is colored laser light different from the white light from a flashlight?**

Name_________________________ Date___________ Period _____

9.b. Summative Assessment (2/4)

4. **In the diagram below,** use a **red** colored pencil to draw the reflected ray from incoming light ray #1. Use a protractor.

5. **In the diagram below,** use a **blue** colored pencil to draw the reflected ray from incoming light ray #2. Use a protractor



6. **Complete the table below:**

Trial Number	Angle of incidence	Angle of reflection
1	60°	
2		45°
3	37°	

Name________________________________ Date___________ Period _____

9.b. Summative Assessment (3/4)

7. **In the table below, describe what happens to light rays when they hit each object. Be sure to describe whether light can travel through the object and whether anything changes about the angles of the light.**

Object	Describe what happens to the light rays
plastic wrap	
black construction paper	
flat mirror	
convex lens	
concave lens	

8. **Choose at least one object from the table that demonstrates:**

a. absorption?

object ____________________________

Why does it demonstrate absorption?

b. transmission?

object ____________________________

Why does it demonstrate transmission?

Name__________________________________ Date____________ Period _____

9.b. Summative Assessment (4/4)

c. reflection?

object _______________________________

Why does it demonstrate reflection?

d. refraction?

object _______________________________

Why does it demonstrate refraction?

9. Explain three things you did in this unit and how they related to the engineering design process.

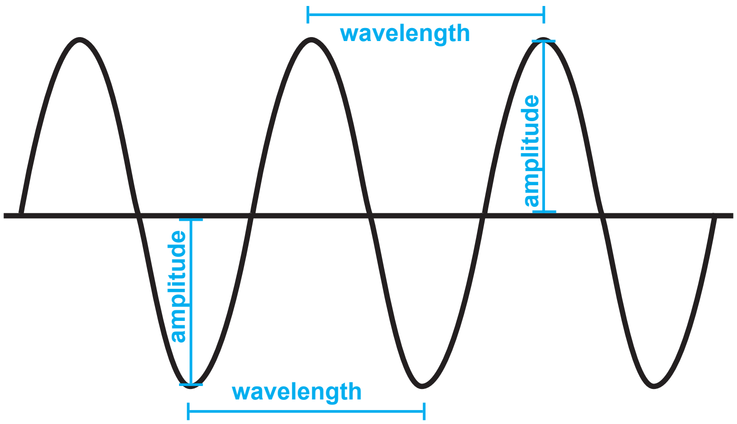
j.

k.

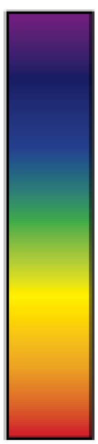
l.

9.c. Summative Assessment Key (1/4)

1. Label the amplitude and wavelength of the wave shown below.



2. Fill in the table below with information about the color spectrum.

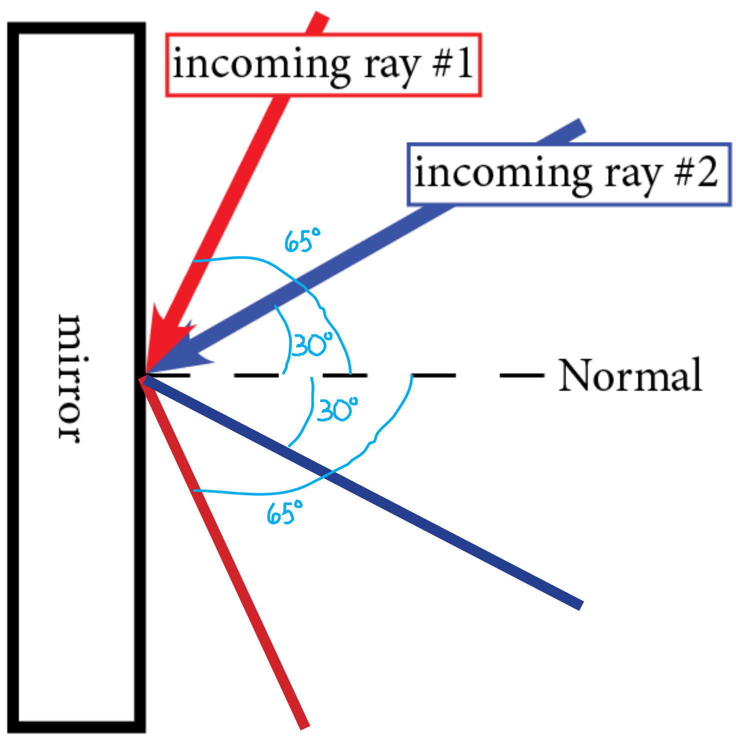
Color	**Energy Levels** (Label the lowest and highest)	**Frequency** (Label the lowest and highest)	**Wavelength** (Label the shortest and longest)
Ultraviolet	**highest**	**highest**	**lowest**
			
Infrared	**lowest**	**lowest**	**highest**

3. Why is colored laser light different from the white light from a flashlight?
Colored laser light has light with only a single wavelength. White light has light from many different wavelengths.

9.c. Summative Assessment Key (2/4)

4. **In the diagram below,** use a **red** colored pencil to draw the reflected ray from incoming light ray #1. Use a protractor.

5. **In the diagram below,** use a **blue** colored pencil to draw the reflected ray from incoming light ray #2. Use a protractor



6. **Complete the table below:**

Trial Number	Angle of incidence	Angle of reflection
1	60°	**60°**
2	**45°**	45°
3	37°	**37°**

9.c. Summative Assessment Key (3/4)

7. In the table below, describe what happens to light rays when they hit each object. Be sure to describe whether light can travel through the object and whether anything changes about the angles of the light.

Object	Describe what happens to the light rays
plastic wrap	**Light travels through**
black construction paper	**Light is absorbed**
flat mirror	**Light is reflected at the same angle it hits the mirror**
convex lens	**Light is reflected and refracted. The light comes together at the focal point on the opposite side of the lenses from the flashlight.**
concave lens	**Light is reflected and refracted. The light spreads out on the opposite side of the lenses from the flashlight.**

8. Choose at least one object from the table that demonstrates:

a. absorption?

object: **black construction paper**

Why does it demonstrate absorption?

the light is absorbed by the paper and does not travel through it or reflect

b. transmission?

object: **plastic wrap or lenses**

Why does it demonstrate transmission?

the light will travel through these materials

9.c. Summative Assessment Key (4/4)

c. reflection?

object: **mirror**

Why does it demonstrate reflection?

the light will bounce off the mirror and travels back on the same side as the light source

d. refraction?

object: **lenses**

Why does it demonstrate refraction?

the light will travel through the lens and come out at a different angle on the other side

9. **Explain three things you did in this unit and how they related to the engineering design process.**
Answers will vary. Students should give specific examples of things they did in the unit and relate them back to the Engineering Design Process. For example, a student could say:

   a. **We read 2 letters from the client that helped us understand the problem better.**

   b. **We made a plan for our design by drawing it out on a piece of graph paper and labeling the angles.**

   c. **We did a redesign after testing out laser security system so that we could improve it.**

Notebook Prompts and Titles

Teacher Directions:

If you prefer to have students write the answers to prompts right in their notebooks (rather than on the handouts and then adhere them to the notebooks), you should have the students put the bold title for each prompt and then answer the question that follows. The format for each will be as follows:

Prompt title:
Question to answer

Have students answer each set of questions as they appear in the curriculum. If any questions are included in the curriculum, but not included here, you may determine the title for the prompt.

Problem Scoping Lessons - Define and Learn

Section 1:

Engineers:
What do engineers do?
Solve Problems:
How do engineers solve problems?

Section 2:

Questions for client:
What are at least 3 questions that you want to ask the client that will help you understand the problem better? Make sure to ask about all important aspects of the problem.

Section 3:

Client:
Who is the client?

Problem:

What is the client's problem that needs a solution? Explain why this is important to solve. Use information from your client to support your reasons.

End-users:
Who are the end-users?

Criteria:
What will make the solution effective (criteria)? Use detailed information you have from the client.

Constraints:
What will limit how you can solve the problem (constraints)? Use detailed information you have from the client.

What we need to learn:

Think about the problem of protecting valuable artifacts. In terms of securing the traveling museum exhibit artifacts, what are at least 2 things you need to learn in order to design a successful laser security system?

Generate Ideas/Plan Lessons

Section 1:
EBR Graphics can just be drawn in notebooks.

Section 2:
Have students answer the following after EBR graphics are complete.

Pros and Cons:
What are the pros and cons of each of your own solution ideas?

Why we chose our solution:
Which solution did your team choose and why? Provide evidence for your reason.

Test Solution Idea(s) Lessons

Section 1:
Ask students to complete after they have run their tests.

Test results:
What were the results of your test(s)?

Learned from test results:
What have you learned about the performance of your solution from your test results? Explain both the things that worked and did not work.

Changes from test results:
What changes will you make to your solution based on the results of your tests?

Reason for changes:
Why will you make those changes? Think about the results of your test and the science and mathematics you have learned.

Section 2:
Section 2 questions should come after the students have run their tests and have had an opportunity to answer Section 1 questions.

How solution meets criteria and constraints:
In what ways does your solution meet the criteria and constraints of the problem?

How solution does not yet meet criteria and constraints:
In what ways does your solution not yet meet the criteria and constraints of the problem?

Notebook Prompts and Titles

Redesign Lessons

Ask students to complete after they have run their redesign tests.

Test results:
What were the results of your test(s)?

Improvement?:
Did your redesign improve your solution? Why or why not?

Next ideas for improvement:
If you could do another redesign, how would you try to improve your solution?

Final Solution Lessons

Section 1:

Students use evidence-based reasoning in reporting their final solution to the client. This can happen through use of the EBR graphic as part of their memo or presentation, or you can have the students include the aspects of the EBR graphic (without the graphic itself) in the memo or the presentation.

Section 2:

These questions should be completed after presenting the solution to the client and the entire design challenge is complete.

Understanding of the problem:
How has your understanding of the problem changed during the design process?

- Look back to the places where you defined the problem in your engineering notebook.
- Think about client needs, criteria/constraints, and science/mathematics needed to solve the problem.

Understanding of designing a solution:
How has your understanding of how to design a solution changed during the design process?

- Look back in your engineering notebook to see how you developed your solution throughout solving the problem.
- Think about what you did and how you made decisions to solve the problem.

