Name ______________________________ Class ______ Date ________

STEM Lab

STEM Quest

An Optimal Optical Solution: Design to Stop a Thief

How can you design and test an optical security system that uses mirrors and lenses to direct light waves where you want them?

Teacher Support

Focus on Next Generation Science Standards This lab builds toward mastery of PEs MS-PS4-2, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, and MS-ETS1-4. Students will apply the following practices, ideas, and concepts in this activity.

Science and Engineering Practices	Connect to the Core Idea	Crosscutting Concept
• Develop and use a model to describe phenomena. • Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim. • Conduct an investigation and evaluate the experimental design to produce data to serve as the basis for evidence that can meet the goals of the investigation. • Apply scientific ideas or principles to design an object, tool, process, or system.	• When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. • There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. • A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. • Although one design may not perform the best across all tests, identifying the characteristics of the design that performed best in each test can provide useful information for the redesign process—that is, some of the characteristics may be incorporated into the new design. • The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution.	Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.

Group Size 2–3 students

Class Time 45 minutes

Safety

1. Urge students to use caution, as mirrors and lenses can chip or break easily, exposing the students to sharp edges.
2. Caution students not to use the mirror or lenses to look at the sun.
3. Remind students to be careful moving around when working in a darkened room to avoid colliding with objects and other people and injuring themselves.

Advance Preparation

Gather materials in advance. Note that lenses that have a focal length of less than 100 mm work best. Also, flashlights must be strong enough for the light beam to travel the total distance to their target. Before the investigation, check to make sure flashlights are in working order, and replace batteries and bulbs as needed. Additional materials include clamps, ring stands, tape, wooden blocks, rulers or meter sticks, flashlight with batteries, and black felt. (All of these materials are included in the Master Materials List for this topic. Quantities given on the Master Materials List are sufficient for each group of students to build the Sample Design outlined below.)

Alternative Materials
You may wish to use plastic rather than glass lenses and mirrors to lessen the chance of breakage and injury from sharp edges. Books may be used in place of wooden blocks.

Procedure Tips

1. Review with students what they have already accomplished in the Quest. Review the concepts of reflected and transmitted light. Preview what students will do in this investigation, and make sure students understand what is expected of them.

2. The Master Materials List for this topic ("Waves and Electromagnetic Radiation") includes enough materials for each group of students to build the Sample Design outlined below; however, students should be encouraged to come up with their own designs as much as possible.

3. If materials or space are limited, consider having students work in groups to set up and share the targets and test their solutions.

4. Make sure student designs are practical before they start building their prototypes. Designs must require the light to travel no more than 1 meter total. (Designs that require the light to travel farther than 1 meter may encounter difficulties related to the intensity of the flashlight beam.) Note that lenses and mirrors may be placed at different heights and different angles to one another to direct the light as desired. Students may use clamps, ring stands, tape, and mirror clips to set the mirrors and lenses at different heights.

5. Although a Sample Design is provided below in case students have trouble coming up with an original design that meets the criteria and constraints, encourage students to construct their own design rather than using the Sample Design as a default.

6. Sample Design: This design uses two mirrors and one lens with a focal length of 10 cm. For a target, it uses a wooden block lying on its side within a U-shaped collection of wooden blocks that are standing vertically, surrounding the target on three sides. Procedure: **(1)** Lay one wooden block down on a flat surface; this is the target block. **(2)** Construct a "U" out of approximately 9 more wooden blocks that are standing up vertically, surrounding the target block on three sides. **(3)** On the "open" side of the U, place a box that is about as wide as the U is wide and that is taller than the height of the vertical blocks. **(4)** Place the lens in a clamp, then tape the clamp to a ruler. Tape the ruler to the top of the wooden box. **(5)** Use a clamp and a ring stand to angle a mirror facing up at about 60° toward a second mirror that is clamped to a second ring stand at a higher height than the first mirror. Note: Arrange the mirrors, box, and target block such that the box is between the mirrors and the "U"; that is, the mirrors should be in front of the box, with the lower mirror to the left of the box and the higher mirror to the right of the box. The lower mirror should be about the same height as the lens; the higher mirror should be somewhat higher than the lens. **(6)** Angle the second (higher) mirror so that it faces about 45° down toward the lens. **(7)** Retrieve a flashlight. **(8)** To help guide the beam of the flashlight, wrap black felt around the perimeter of the flashlight (near the lens). The felt should extend up above the lens of the flashlight. **(9)** Dim the room lights. Aim the flashlight beam at the first (lower) mirror. **(10)** If the mirrors, lenses, and target are positioned at the right heights and proper angles, the light should hit the lower mirror, reflect up toward the higher mirror, reflect down and across to the lens, pass through the lens, and hit the target block.

7. If some student teams have an easier time meeting the criteria and constraints in their design than others, consider challenging them by changing their criteria and constraints. For example, require them to use one less lens or mirror.

8. If time permits, students can continue to redesign, rebuild, and retest their systems, although they are not required to do so.

TE Annotations

1. Sample Answer: how to direct light around an obstacle that partially blocks a target so that the light hits the target

2. Sample Answer: I must use a flashlight as my light source. I must use at least one lens and two mirrors to direct the light around the obstacle. The light must travel a total distance of 1 meter or less.

3. Sample Answers: Light is reflected by the flat silver of a mirror so that it changes direction. It is reflected at the same angle at which it strikes the mirror. Light is transmitted and focused by the outward curving shape of a convex lens. Light is transmitted and spread out by the inward curving shape of a concave lens.

4. Look for answers that show an accurate understanding and application of the Quest design constraints, such as the use of one or more lenses and two or more mirrors.

5. Students should list all the materials, specifically a flashlight and the number of plane mirrors, concave lenses, and convex lenses needed. Students will also need materials to support the mirrors and lenses so that they are free-standing. Suitable materials include clay, putty, or mirror clips and lens clips.

6. Look for answers that show an understanding of how light is reflected or transmitted by mirrors and lenses, as well as a description of how the parts of each design solution will work together to direct the light to the target.

8. Students' drawings of their solutions should be to scale, and detailed, and should include labels for all parts.

9. Look for observations that are detailed and accurate.

10. Look for observations that are detailed and accurate.

11. Look for observations that are detailed and accurate.

12. Students' answers should evaluate how well their last solution in Step 11 did at hitting the target and state whether the parts of each solution functioned as they expected. Students should cite evidence from their tests.

13. Look for answers that describe one or more ways of making students' solutions perform better at hitting the target. Students might suggest using an additional convex lens to better focus the light and an additional mirror to better direct the light around the obstacle.

15. Students' presentations of their final solutions should include diagrams that are to scale and detailed, and should include labels for all parts. The presentation should explain and illustrate how the solution solves the problem of hitting the target.

16. Students' answers should explicitly describe the strengths and weaknesses of their solution. Students' evaluations of their system's design and performance should be thoughtful and detailed.

17. Students' models should incorporate their final design solutions.

18. Students' answers should explain where light would be reflected, absorbed, and transmitted in their model. They should explain that the mirrors reflect the light, the lenses transmit the light, and other materials in their models absorb the light. Students should recognize that the mirror used in their system reflected light waves when the light bounced back. They should also recognize that light waves were transmitted through the convex and concave lenses.

TE Annotations: Quest Follow-Up

1. Students should note that the energy loss might have come from the spreading out of the light beam.

2. A laser would result in less loss of energy.