JV InvenTeams™ - Super Lens

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Welcome to JV InvenTeams, where students develop skills in science, technology, engineering, and math (STEM) through fun, invention-based design activities and challenges.

About Lemelson-MIT

The Lemelson-MIT Program (https://lemelson.mit.edu) is dedicated to honoring those who have helped improve our lives through invention. The Program was established in 1994 at the Massachusetts Institute of Technology (MIT), by one of the world’s most prolific inventors, Jerome Lemelson (1923 -1997), and his wife, Dorothy. It is funded by The Lemelson Foundation and administered by MIT’s School of Engineering. The Lemelson-MIT Program recognizes outstanding inventors, encourages sustainable new solutions to real-world problems, and enables and inspires young people to pursue creative lives and careers through invention.

The Lemelson-MIT Program encourages great inventors through various outreach programs such as InvenTeams (https://lemelson.mit.edu/inventeams), a national grants initiative for inventive high school students who have a strong foundation in scientific and technical skills. InvenTeams are teams of high school students, teachers, and mentors that receive grants of up to $10,000 to invent technological solutions to real-world problems. The Lemelson-MIT Program developed JV InvenTeams in order to reach slightly younger high school students and provide them an introduction to inventive thinking and doing.

About JV InvenTeams

The goal of JV InvenTeams is to cultivate new ways of thinking and develop technical skills for students with limited access to hands-on STEM enrichment opportunities. Through prescribed activities, students will add to their own “toolkits” of minds-on knowledge and hands-on skills while having fun!

Students will learn how to identify a need in their lives or in the world around them and to develop their own invention after completing the main activity in each unit. They will pull from their expanding toolkit to come up with solutions.
JV InvenTeams Activity Guide Components

Each unit of JV InvenTeams activities is presented in the same format. The Educator Guide includes specific notes and segments, while the student version is more streamlined and includes working space for the students. The educator may decide how much of the information should be shared with the students and in what manner – e.g., read out loud or individually. Each meeting within the unit is estimated to take between 1.5 and 2 hours to complete.

Each group of young people will be different, so the pace of each unit is up to the educator. Know that there are numerous resources to balance the unit to meet your needs. Some may find that breaking units into a couple of sessions will allow the think-time needed for your group. Others may want to streamline items and skip some of the videos.

Each unit has the following in the first pages:

- Title page with summary of the unit and learning objectives
- Summary of each meeting within the unit
- Master consumable materials and tools lists
Students may ask, “Why should I invent?” Here are some of the reasons you can share during the first meeting. Invention...

- solves world problems like finding clean sources of energy and treating unsafe water;
- helps people;
- allows people to explore a creative process that often involves teamwork;
- provides fulfilling careers: inventors are often scientists and engineers who improve areas of health, energy, food and transportation;
- can also lead to a high-paying career with many job opportunities as an engineer or scientist; and
- is fun!

**Group size**

JV InvenTeams is recommended for approximately 20 students in Grades 7, 8, 9 and 10. Most activities require students to work in teams of four.
Partnerships

The Lemelson-MIT Program encourages participating schools to seek community partnerships to sustain JV InvenTeams. Partnership opportunities include:

- Science and technology museums, to provide direct mentoring;
- Local technology and engineering companies, to provide funding for future extension ideas, materials, or mentors;
- Local universities or colleges, to provide collegiate mentors; and
- Hardware stores, to provide tools or materials.

Flexibility

JV InvenTeams has built flexibility into the program to meet the needs of educators, school systems, and grants-based clubs and organizations. Following are some examples:

- Each unit is designed to stand on its own. Educators can lead one unit, a few units or all of the units.
- The program can be held in any educational setting with a science or technology educator facilitating the activities.
- Each unit has approximately 6 meetings of 1.5 - 2 hours’ duration.
- Meetings can take place multiple times a week or once a week.

Inventive Thinking

Both educators and students will develop an understanding of the invention process as you navigate through JV InvenTeams. This new way of thinking, part of the minds-on toolkit, may take some time to adopt since learning within the school day increasingly focuses on standardized tests of academic knowledge. Invention is a variable, non-linear process. JV InvenTeams introduces the curiosity and creativity of recognizing problems and addressing them with novel solutions. You will not need to worry about knowing the “right” answer since there are countless possibilities. Experiencing failure is part of the invention process.

Inventing is creating something new that is useful or helpful, by means of one’s own investigation, experimentation, and thinking. An invention is the product of the inventing process. It can be a device, a material, a system, and even a plant. Invention refers to a new physical thing made possible by technology for the purposes of JV InvenTeams. Inventive thinking challenges what people come to expect or anticipate. Revolutionary inventions, known as macro-inventions, make a huge impact on the way we live. Examples include the internal-combustion engine for the automobile and the integrated circuit for consumer electronics. Most inventions are micro-inventions, or adaptations that grow from larger-scale inventions. This means making an existing product faster, stronger, cheaper, easier, safer, more efficient, or more useful.
User-Centric

The key to inventing is to make sure the invention is user-centric. This means that students need to think about and understand problems affecting real people and their specific needs. Researching the unique characteristics and needs of the user is essential to coming up with an effective design – as is working directly with them! Students will develop empathy for the beneficiary during the process.

An example of this would be a student noticing that his or her grandmother has difficulty moving around the house in her slippers, due to slippery floors. The student should investigate by first asking his or her grandmother:

- Do you wish your slippers had a better grip?
- What parts of the slipper do you like? What parts would you change? Why?

After learning from the user, the student can further investigate. Questions he or she might ask include the following:

- Does the solution lie in changing the floors or the footwear?
- How can I change her slippers to make the grip better?
- Is there another product on the market that provides the ease and comfort of slippers with the safety features of shoes with more grip?

These questions will inform research and allow the student to develop meaningful solutions.

Deciding on a Good Problem to Solve

Identifying a good problem to solve can be challenging, but it is just like any other skill: it becomes easier with practice. Therefore, at the beginning of each unit in JV InvenTeams, students will be given a problem or scenario that requires devising an original solution. Coming up with solutions to problems can be difficult at first, but students will gain confidence in generating new ideas over time. One way to accomplish this is through transgressive thinking – applying flexible or “out of the box” thinking in one area to another. The SCAMPER technique is a good technique to start with because it provides a framework to come up with solutions.

SCAMPER

The SCAMPER brainstorming technique was developed by Bob Eberle and published in a book by the same title. SCAMPER is based on the notion that something new can be modified from something that already exists. Each letter in the acronym represents a different way you can mentally view the characteristics of the challenge. It’s a “mash-up” of disparate things to conceive something new.

- S = Substitute (playing basketball with a softball)
- C = Combine (toothbrush combined with a pencil to create a new product)
- A = Adapt (how would you eat your spaghetti without a utensil?)
- M = Magnify (how would your chair function if the legs were wider and longer?)
- P = Put to Other Uses (could your fork be used as a comb?)
• E = Eliminate (could you play tennis without a racket?)
• R = Rearrange (what if the laces of a shoe were placed on the bottom and not the top?)

The SCAMPER technique involves the students first stating the problem they would like to solve, which defines the challenge. Then it's a matter of asking questions, using SCAMPER to guide the students. No idea is a “good” or “bad” idea at this point.

Documentation

Students should be encouraged to document their progress along the way. This includes saving sketches, designs, research data, graphs, images, and early prototypes. Most of this work, with the exception of the actual prototypes, can be compiled in the student guides. Students should routinely review their guide, adapting what they have learned and experienced to new challenges.

Patents

Since this program is all about invention, it is important that educators and students familiarize themselves with the United States laws that protect the intellectual property of inventors. A patent is one type of intellectual property that can be legally protected through the U.S. Patent and Trademark Office (USPTO). The other types of intellectual property are trademarks and copyrights. A trademark includes any word, name, or symbol used to distinguish one manufacturer from another (e.g., brand name). Copyrights are recorded with the U.S. Copyright Office in the Library of Congress for original authored works like books and music.

According to the U.S. Patent and Trademark Office, patents provide legal protection to inventors’ intellectual property by excluding others from profiting from their property in the U.S. for a specific amount of time, in exchange for the inventors’ disclosure of their idea according to the criteria for granting a patent. There are three different types of patents. Utility patents are granted to inventors who discover a new and useful process, machine, article of manufacture, or a new and useful improvement. Design patents are granted to those who invent a new, original, and ornamental design for an article of manufacture. Finally, a plant patent is granted to an inventor who invents a new variety of plant. The basic components of a U.S. patent are: patent number, title, inventors, assignee (optional transfer of intellectual property to a company or other individual), abstract (short overview of invention), drawings, description (technical details), and claims (legal information). To learn more about the patent process, visit: [http://uspto.gov/](http://uspto.gov/). Students will be required to search patents to ensure that their idea is unique. Patent searches can be done through Google Patents and Free Patents Online. Both have easier search functions than the U.S. Patent and Trademark Office.

Jerome Lemelson, founder of The Lemelson Foundation, had a productive life as an inventor, holding more than 600 patents. He was awarded his first patent in 1953 for a toy cap, and spent the next 45 years coming up with inventions that led to products such as bar code readers, automatic teller machines, cordless phones, cassette players, fax machines, machine vision, and personal computers.

It is important to keep in mind that not all inventions are patented. Some inventors purposefully do not seek a patent with the idea that their inventions are immediately and widely available. An example is open source software, which allows anyone to use the software without paying a fee. This openness can spur further invention since anyone can access it and make adaptations. In spite of the changes in patent law through the Innovation Act of 2013, students should adopt the habit of recording and dating their work, including early sketches and research. This practice will be useful for future science exploration and invention. To learn more, visit: [https://govtrack.us/congress/bills/113/hr3309](https://govtrack.us/congress/bills/113/hr3309).
Unit Summary for Students

This unit will guide you to create lenses that meet the needs of a chosen user.

Many photographers who use smartphone cameras, from consumers to professionals, desire more sophisticated optical features for their devices, from an optical zoom to ways to adjust image settings. You will learn how to control light through hands-on activities, testing various lenses, and optical concepts. You will also explore scientific, health care, and entrepreneurial trends in camera phone lenses currently in development. You will design prototypes of a working smartphone lens using glass lenses and cardboard, and will be able to focus an image on a vellum paper screen, change the optical properties, and capture an image. Principally, you will learn two things: how a lens’s shape and material affect focal length and how focal length affects angle of view and zoom.

You will gain both minds-on and hands-on skills in this unit to expand your toolkit. Minds-on skills include looking toward nature for insight into how humans and other species achieve vision. You will learn how to calculate refractive index and focal length. You will also learn about the design process—identifying a problem, brainstorming, researching, “getting into the shoes” of the prospective user, sketching ideas, building, and testing.

Hands-on skills will include how to cut and shape cardboard, test optical properties, focus lenses, and capture images. At the end of the unit, you will draw on these new skills to brainstorm an invention of your own. You might design a new camera or use the prototyping process to create an entirely different type of optical device in the service of assistive technology or health care or another field. You will learn to be an inventive thinker as you progress through this unit.

Learning Principles

Design Process
Optical Calculations
Materials
Prototyping
Meeting Synopses

1 **Invention Introduction (included in every JV InvenTeams unit)**
   Introduction to invention and JV InvenTeams. Do warm-up activities and discuss invention. Play “Four Corners” to determine your strengths for team assignment.

2 **Light Rays & Lenses**
   Take apart a smartphone to examine its camera, including the optics and the image sensor. Learn how others are improving smartphone lenses, drawing inspiration from human and animal vision. Learn to calculate the refractive index of a lens material.

3 **Sketch & Design**
   Shine light beams through various lenses to learn how light bends. The educator introduces the main design challenge of the unit. Your teams begin researching various users of cameras and lenses. Learn to cut cardboard safely.

4 **Test Components**
   Your team calculates focal lengths of various lenses. Based on calculations, you will find a lens that suits their chosen design.

5 **Build a Lens**
   Learn to create a prototype. Teams build a lens prototype out of glass lenses and cardboard, and test for focus and brightness.

6 **Take Digital Photos**
   Capture images on your prototype lenses using a smartphone, evaluating properties such as optical zoom and angle of view. Learn about real-world invention from an engineer of low-cost optometry equipment, energy turbines, and robots. Teams use their toolkit of new skills to brainstorm ideas for inventions using lens design, optical concepts, and the prototyping process.

7 **Invention Extension**
   Display your images in printed form and provide feedback to other teams. Conceptualize a new purposeful invention that uses lens design, optical principles, and the prototyping process.
Super Lens
Meeting 1: Invention Introduction

Procedure

- Get Your JV InvenTeams Guide
- Introduction to Invention and Problem Solving
- Design a Cell Phone Stand
- Think About Your Invention
- Watch Invention Videos
- Research an Invention
- Discuss Improvements to an Invention
- Investigate Real-World Improvements
- Watch Videos about the Design Process
- Set Rules and Develop Teams
- Self-Assessment

Your Guide

1. You will use your JV InvenTeams guide as an invention guide. This guide will be a portfolio of your work and ideas.

2. The grid paper and blank paper at the end of each meeting can be used to sketch, brainstorm, and document ideas.
Introduction to Invention and Problem Solving

1. We all run into challenges on a daily basis. You will now get a taste of what being an inventor means by coming up with ideas to address some of these problems.

2. Your educator has written down some problems on strips of paper. You will work with a team to build a solution to one of these problems using everyday materials.

3. After you receive your problem, use the recycling bin to find building materials and work with your team to devise a quick invention to meet your need.

4. When you are finished, take turns sharing your simple solutions with the full group. Some questions to ask other groups include:
   • How would you change your invention if you had more time?
   • How would you change your invention if you had a bigger budget?

5. Inventors often use inexpensive, everyday materials to create prototypes of their inventions. That’s because they don’t want to waste expensive materials in the early stages of designing. Failure and mistakes are common and part of the process.

Hands-On and Minds-On
MIT’s motto is Mens et Manus, which translates to Mind and Hand. Inventors are resourceful and use many tools. Some “tools” are based on learned knowledge stored in our minds from science and math classes. Other “tools” are practiced – hands-on skills like drawing and building things.

Early prototypes of the Polaroid camera from the MIT Museum collection
Design a Cell Phone Stand

1. Do you ever get annoyed by your phone not being able to stand up on its own? Inventors think outside of the box and create prototypes of their ideas using everyday materials.

2. Your challenge is to invent a low-cost cell phone stand using recycled materials like cardboard. You can also use duct tape.

3. Before you start, watch Josh Ramos’ Cardboard Videos to learn some cardboard cutting tips and tricks. Josh is a PhD candidate in Mechanical Engineering from MIT.

4. If you are having difficulty coming up with your own design, check out Josh Ramos’ Cardboard Phone Stand.

Think About Your Invention

1. What do you like about the stand you made?

2. How would you change your design if you wanted to watch a video in the landscape format (sideways)?

3. Where are the speakers on your phone? How might you use the placement of the cardboard or other materials to improve the sound?

4. Share your design with another student. Write their feedback below:
5. How would you incorporate your and their comments in your next design? Describe this next design iteration in words or pictures.

During the JV InvenTeams initiative, you will learn about new tools and materials through invention activities like this one. You will think of iterations to improve your design after successfully meeting these challenges.

Watch Invention Videos

1. Each year, teams of undergraduate and graduate students apply for the Lemelson-MIT National Collegiate Student Prize Competition. Check out some cool videos from previous winners and finalists:

- **Alice Chen's Inventions Make Our Lives Healthier** (2:27)
- **Ben Peters' Inventions Make Our Lives More Engaging** (1:57)
- **Eduardo Torrealba's Inventions Make Our Lives Easier** (first 9 min)

2. All good inventions, including the ones presented in these videos, stem from a real problem or need. Most inventions do not produce radical change in society, but rather build upon previous inventions to make aspects of life easier, safer, more comfortable, more engaging, and/or healthier.

Invention Research

1. Identify an object in the room.

2. We often take the daily products and tools in our world for granted. Each of these items has a history of evolution. Scientists, engineers, and designers made modifications over time that produced the modern object you see today.

3. You will conduct research on inventions using Google Patent Search. Google Patents lists U.S. patents as well as international patents. Patents are sequentially numbered; for example, search for “student desk” and look at the images for US7571959B2.

MIT alumna Alison Wong invented Keyprop™, a simple solution to the problem of keeping your smart phone propped up. Check out a video of her invention: Invention Profile: Keyprop.
Super Lens  
Meeting 1: Invention Introduction (cont.)

   • How can this product continue to improve?

   • What information can you gather from the technical drawings? Why are detailed images such an important part of a patent?

Discuss Improvements to an Invention

1. Think about a timeline of your daily routine. If you could improve one product or process during your typical day, what would it be?

2. In your group, discuss the following:
   • How might you go about making the improvement? Describe your process.
   • What might be some challenges to meeting this need?
   • Thinking further, do you notice anyone in your family or community who struggles to complete a certain task? What invention might improve this aspect of their life?

Investigate Real-World Improvements

• **Sesame Ring**: Several MIT undergraduate students were having difficulty locating their reusable train tickets upon entering the train station. Their solution is a wearable reader in the form of a customizable ring.

• **Tile™**: Do you ever have difficulty finding your keys or wallet in your home? The solution is a small piece of plastic with a chip that connects to an application on your smartphone.
• **uBeam**: Meredith Perry, a graduate of the University of Pennsylvania, was sick of long electrical wires for laptop computers. She started a company, uBeam, that is working on a wireless charger.

**Watch Videos about the Design Process**

1. Watch the [MIT Design Process Videos](#).

2. Draw a visual model or outline below that will help you remember the steps of the design process as you invent something.

| ![Blank space for visual model](#) |

**Set Rules and Develop Teams**

1. The JV InvenTeams initiative is all about hands-on fun. Here are a few important rules to follow to make this possible:

   • Safety is the number one priority! Watch tutorial videos before using new tools and materials.
   • Ask for help. Don’t guess, especially about how a tool works.
   • Consider all ideas. No idea is “dumb.” As an inventor, focus on the ideas with the most potential when developing a prototype.
   • Embrace failure. Failure is a part of the invention process!
   • Value your team. Everyone brings different skill sets and knowledge to the table.

2. Diverse teams are successful teams

3. Play a game called “Four Corners” to help the educator create balanced teams. Instructions are on the next page.

**Design Process Notes**

Steps of the design process are:

• identifying needs,
• brainstorming ideas,
• sketching,
• building a prototype,
• testing,
• modifying, and
• re-testing.

**Extend the Learning**

You can continue exploring invention by researching well-known inventors in your community. How? Go to [Free Patents Online](#). The login is free. Click on the Search tab, then use the “Quick Search” feature to enter your location under “Inventor Fields.” You may want to search chronologically by the last 20 years.
Name: ___________________________

Four Corners Game

Teams of inventors include people with different interests and skills. In order to organize into teams, think about your own interests and skills.

Draw lines from the items on the left to the best-matching description on the right.

**Types of Team Members**

- **Tinkerer:** I like to take things apart and build things.
- **Talker:** I like to talk to people and I enjoy public speaking.
- **Doodler:** I like to draw things and express my thoughts through drawing.
- **Organizer:** I like to organize people and things.

**Your Interests and Skills**

- Sounds most like me
- Sounds almost like me
- Sounds a little like me
- Sounds least like me

The corners of your classroom will be marked with the four types of team members. Go to your “sounds most like me” description of yourself. Your educator will make balanced teams using this information.
Super Lens
Meeting 2: Light Rays & Lenses

KEY TERMS

CCD sensor (n): Used in camera phones and other digital cameras. The "charge-coupled device" sensor changes light into electrical charges that a computer chip can read as an image.

CMOS sensor (n): A newer, alternative type of sensor used in camera phones and other digital cameras. The "complementary metal-oxide-semiconductor" sensor also changes light into small electrical charges, but each sensor contains its own amplification system.

Converging lens (n): A lens that concentrates light, also called a convex lens. The shape has a round part that is thicker in the middle.

Entrepreneur (n): A person who organizes and operates a business, taking on financial risk to do so.

Fresnel lens (n): A lens that concentrates light like a converging lens. These are often very big, with lower quality than traditional lenses, but flat and low-cost. Fresnel lenses are commonly used in overhead projectors.

Image sensor (n): A device inside a smartphone camera or digital camera that collects light and turns it into electrical signals, which are then turned into pictures. The two types are CCD sensors and CMOS sensors.

Lens (n): A transparent material like glass or plastic that focuses light and creates an image.

SDS (n): Safety data sheets provide users with procedures for safe handling when working with substances. The SDS also includes helpful information like a list of chemical components, toxicity, health effects, first aid, storage, and protective equipment needed.

Procedure
• Introduction to General Shop Safety
• Take Apart a Smartphone with Camera
• Digital Cameras Use Image Sensors
• Li Han Chan and Kevin Cheo Improve Smartphone Cameras
• Snell’s Law
• Calculate the Refractive Index of a Lens
• Review
• Self-Assessment

INVENTOR’S TOOLKIT

Hands-on
• Carve shapes
• Measure angles

Minds-on
• Learn about lens properties
• Identify an image sensor
• Calculate refractive index
• Learn about eye safety
Introduction to General Shop Safety

1. Shop safety is of the utmost importance so that nobody gets hurt. You will be using hand tools such as utility knives. Tools should always be used in the way they were designed to be used. Watch a general shop safety video (10 min).

2. Review the general shop safety rules:
   - Wear safety glasses.
   - If you are in doubt about how to use a tool, ask!
   - Have a plan for what you are going to do with the tool.
   - Be mindful of others who might enter into your working space accidentally.
   - Secure the workpiece.
   - Have a balanced stance while using a tool.
   - Remove all jewelry, watches, and loose clothing before working with machinery.
   - Pin up long hair and wear closed-toe footwear.
   - Never work when you are tired or not focused.
   - Leave the workspace cleaner than you found it.

Take Apart a Smartphone with Camera

1. Gather into your teams. Each team will be given an inexpensive smartphone and cell phone pry tools.
2. Put on safety glasses and rubber gloves for this activity. Cell phone circuits contain toxic materials such as lead, mercury, arsenic, cadmium, chlorine, and bromine.
3. Review the instructions below on how to dissect a smartphone with a camera, and then you can get started.
   - Remove the battery cover from the phone.
   - Use a screwdriver to remove the screws on the back of the phone.
   - Use the plastic phone pry tool to remove the screen from the plastic case on the back of the phone.

KEY TERMS (CONT.)

Normal (n): A line perpendicular to a surface.
Photodetector (n): A single light sensor in a digital camera. Most devices have many millions in order to capture a full image.
Photon (n): A particle of light energy.
Photoreceptor (n): A single light sensor in the human eye. The human retina has about 120 million of these.
Pixel (n): A very small illuminated area on a display screen; the word pixel stands for picture element.
Prism (n): A triangular, transparent object with surfaces at acute angles to each other. Prisms can separate white light into a spectrum of colors.
Refraction (n): When a wave of light passes through one type of material to another, such as from glass to air. Light rays often bend through refraction.
Snell's law (n): A way of predicting the direction of light as it travels from one material into another (for example, from air to glass).
Super Lens
Meeting 2: Light Rays & Lenses

- Gently pull out the ribbon-wire connector for the screen from the main circuit.
- Find the camera lens.
- Remove the camera lens from the phone by gently pulling. The ribbon wire connectors will pull loose.
- Unscrew the lens from its housing with a finger or the tip of a pencil by making a counterclockwise motion. Underneath the lens will be the camera sensor.
- Identify the converging lens, the Fresnel lens for the flash, and the CCD sensor. If the smartphone has a flash feature, then it will have a light source and may include a Fresnel lens.

4. Did you think the take-apart process was simple? Many inventors are trying to find ways to put more useful lenses into smartphones. One of the challenges engineers have is squeezing lenses into such a small space.

SUSTAINABLE SOLUTIONS

It’s important to recycle or reuse old cell phones. When they end up in landfills—as about 70 million do worldwide every year—they risk leaching hazardous amounts of lead and other metals into the ground. One solution for old phones is to exchange them for cash or donate them to a charity. Can you find a charity that accepts donated cell phones?
Digital Cameras Use Image Sensors

1. Read the following paragraphs about digital camera sensors:

The heart of any digital camera or camera phone is the image sensor. These sensors come in two different types—CCD sensors (charged-coupled device sensors) and CMOS sensors (complementary metal-oxide-semiconductor sensors)—but they work in a similar way. Photons enter a tiny component on the surface called a photodetector and create a small electrical current that is interpreted by the computer chip inside the camera. Each photodetector is called a pixel, and some are in charge of detecting red light, some green light, and some blue. The color information goes to a computer chip in the smartphone that combines the data to create a color image.

Today, most smartphones use the newer type of sensor—the CMOS—which is less expensive to produce in large volumes because they’re made in a general-purpose microchip factory. CMOS sensors also use less power and take photos more quickly.

2. Answer these questions:

• What does a sensor do?
  ____________________________
  ____________________________

• What are the two kinds of sensors?
  ____________________________
  ____________________________

• Where is the sensor located in a smartphone in relation to the lens?
  ____________________________
  ____________________________

In 1823, a new kind of lens was used to send light much further from a lighthouse than ever before: its light could be seen for more than 20 miles from the French shore. It was a strangely flat lens that concentrated light by using rows of small prisms along its surface. It was developed by French physicist and engineer Augustin-Jean Fresnel.

Fresnel lenses work just like camera lenses, except they are completely flat and are often much cheaper to make. Today they are used to help people see reading materials and to focus the image on big-screen TVs. Learn more here: http://uslhs.org/history/fresnel-lenses

A Fresnel lens. Credit: Adolphe Ganot

EXTEND THE LEARNING
Li Han Chan and Kevin Cheo Improve Smartphone Cameras

1. Read the following profile of entrepreneur Li Han Chan.

Inventor Kelvin Cheo and entrepreneur Li Han Chan saw a need and filled it. They saw that more people were using smartphone cameras to take pictures instead of using conventional digital cameras. Sales of small, point-and-shoot digital cameras and high-quality digital cameras had decreased dramatically.

Cheo teamed up with Chan, who at the time was working at a venture capital company, an organization that looks for promising technology ideas to invest in. Chan knew that improvements in lenses and optical technologies for phones were starting to show up in the industry, so they founded the startup company DynaOptics in 2012 to bring innovative lenses to smartphone users.

The team wanted to find a way to make the images taken with small, thin smartphone cameras look better. The problem was that the
tiny lenses can’t zoom in on things that are far away. If you zoom in closely by pinching the screen on your phone, images are likely to look blurry.

What did the optics experts come up with? They invented a series of wedge-shaped lenses, stacked on top of one another, that move back and forth. Together, they create a compound lens with a higher or lower refractive index depending on the placement of the elements. Chan describes the design as a bunch of bifocal eyeglasses that shift around to get the best image. Check out the DynaOptics website to see the patented free-form lenses.

Chan grew up in Singapore. Chan is a graduate of Stanford University, and an avid climber, skier, and biker. She hopes that smartphones will one day take pictures of distant objects such as mountains, nature, and beautiful landscapes just as well as expensive digital cameras.

EXTEND THE LEARNING

Your eye has photoreceptors similar to the sensors on a digital camera, except that instead of creating an electrical charge, the eye’s rods and cones produce a chemical signal that is interpreted by the brain. While electronic image sensors and human eyes vary a great deal, it is interesting to compare them. The eye has about 120 million rod and cone cells, while the highest-quality cameras for sale have 80 million electronic photoreceptors.

Your eye sees the image upside down, but the brain reorients it automatically without you knowing—just like a camera lens does!

The human eye sees an inverted image.
Super Lens
Meeting 2: Light Rays & Lenses

Snell’s Law

1. You will be calculating and testing Snell’s Law, which predicts the direction of light as it travels from one material into another. You’ll be exploring refraction. One way to test refraction is to use common cooking gelatin from the supermarket, which they will do later.

2. Read about Snell’s Law and measuring refractive index.

3. Summarize what you learned and ask any questions you might have.

What’s the fastest thing in the universe? Light! But that’s only when it’s traveling through air. What happens when light hits a dense material like water, glass, gelatin, or another clear material? It slows way, way down. And when light travels into denser transparent material at an angle, it bends slightly. That’s a phenomenon scientists call refraction, and it’s what makes it possible for a camera lens to focus light for an image. The way this occurs was described by the 17th-century Dutch astronomer Willebrord Snellius in a principle called Snell’s Law:

Snell’s Law

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]

SAFETY

The red laser pointers you are using in the three milliwatt range will not cause eye damage, according to the American National Standards Institute, but part of your discussion should include how to use them responsibly. Be aware that other lasers, such as green laser pointers and devices of 5 milliwatts or more, can cause eye damage.

These are tools, not toys. Never shine a laser pointer at anyone.
Snell’s Law may look like a complicated formula, but it turns out to be pretty easy. You will get a lot of help from an online calculator when it comes time to plug in the numbers.

The illustration shows two media—air and gelatin, which you will explore in the activity below. The white area represents air, the fast medium. The gray area represents gelatin, the slow one. The line represents the laser beam you will shine through the gelatin during the activity.

Later, you will learn how to calculate the formula step by step. But here is a quick overview of it:

• The Greek letter, theta (θ), represents the angles.
• The angle $\theta_1$ will be the angle of light traveling through the air. You will get the angle value from how they hold the laser pointer.
• The angle $\theta_2$ will be the angle of the light traveling through the gelatin. That’s the number you have to determine using keen observation.
• The value $n_1$ is the refractive index of air, which turns out to be 1.
• The value $n_2$ is the refractive index of gelatin. The value of $n$ has to do with how fast light travels in a material. The slower the light speed, the higher the $n$ value. In this activity, the value $n_2$ is what you are trying to find.

Calculate the Refractive Index of a Lens

1. Use the recipe that follows to make the gelatin at least two hours before the meeting.

Cooking gelatin takes two to three minutes, but it needs at least two hours of refrigeration to set. *Credit: Bob Parks*
Super Lens
Meeting 2: Light Rays & Lenses

Recipe:
This recipe uses plain cooking gelatin, but the result is more than twice as concentrated as the normal Knox recipe for gelatin desserts. The gelatin does not need refrigeration once it is set. It will hold its shape and will not melt at room temperature or even in direct sunlight.

• Make gelatin at least two hours before the meeting. It takes at least two hours in the refrigerator to reach the appropriate texture.
• Pour 1 cup of cold water directly into a bowl. Add six individual packets of cooking gelatin (each package contains four envelopes). Then add 1 1/2 cups of boiling water and stir until dissolved.
• Pour the solution into 4 semicircular refraction dishes to mold the gelatin.
• Cool in the refrigerator for at least two hours or preferably overnight.

2. Use the directions to complete the activity. Each team will be given two laser pointers and a gelatin-filled refraction dish. Skim through the activity before they begin, then carefully follow the directions.

Directions:
• Dip the bottom of the refraction dishes into hot water for 10 seconds to free the gelatin from the edges of the dish. Use a dull knife to loosen the gelatin.

Credit: Eurah Ko
Purpose-drawn Protractor

Place gelatin block here

Aim laser beam here
• One team member from each team should remove the guide page with the purpose-drawn protractor.

• Shake the gelatin slab loose from the refraction dish and onto a piece of wax paper. It may take a few strong shakes to pop it out onto the wax paper. Keep the gelatin on the wax paper throughout the investigation. This will keep the paper protractor dry.

Gelatin on wax paper:

Credit: Eurah Ko

• Each team will use one gelatin half-circle on the top half of the protractor, as shown. Slide the wax paper and the gelatin over the protractor.

Credit: Eurah Ko
Super Lens
Meeting 2: Light Rays & Lenses

- Working in teams, shine the laser pointer beam through the gelatin disk along the 0-degree line on the protractor (see below). This is the empty side of the protractor, with the 0-degree line closest to the student. This line is perpendicular to the flat edge of the gelatin and is called the **normal**.

- Determine the angle at which the beam travels through the gelatin. It should be the exact same angle, or the normal of the gelatin. Here’s why: If you shine a beam straight into the gelatin along the normal line, it keeps going straight. In other words, if a beam of light enters a denser material along the normal, it will continue on at the normal. In this special case, refraction does not cause light rays to bend.

**STUDENT AND EDUCATOR NOTES**

Fantasy FX Professional Haze Spray is a nontoxic mist designed to enhance beams of light in public performances of plays and theatrical productions. The product’s **Safety Data Sheet (SDS)** states that it is made of droplets of mineral oil that will not cause irritation with ordinary use. Use in a well-ventilated area.

**SAFETY NOTE**

Lasers must be handled with care. They can damage eyesight, and should never be pointed at a person.
• Pick an angle on the part of the protractor closest to you and shine the laser beam through the exact center of the gelatin, along that angle line (see diagram below). To help line up the laser beam, have one team member should spray just a little Haze Spray between the laser pointer and the gelatin to make the beam show up. Pick any random angle, such as 10°, 22°, or 57°, but make sure the laser beam is exactly on it. Write the angle on the empty side of the protractor here: _______________.

• Observe the angle of the beam as it goes through the gelatin. Make sure the beam is going through the center dot and is perfectly parallel with one of the angle lines on the empty, air side of the protractor. When you have everything lined up, carefully determine the angle of the light inside the gelatin and write it down here: ______________.

• Now you are ready to use Snell’s Law to find the refractive index of the gelatin. The easy way to do this is to plug the numbers into a simple Snell Calculator, such as the one on the science site Endmemo. Here’s how to do it:

1. Go to the Endmemo site, and where it says “1st Medium Refraction Indices,” fill in the number 1. This is the refractive index of air.
2. Where it says “Angle of Incidence,” enter the angle of the beam traveling through the air. It is the number you wrote down in the first blank space.
3. Leave the spot for “2nd Medium Refraction Indices” blank. That’s the number you are trying to get.
4. Where it asks for “Angle of Transmission,” enter the angle of the beam through the gelatin. It’s the number you wrote down in the second blank space.
Super Lens
Meeting 2: Light Rays & Lenses

1. Finally, press the Calculate button. Write down the number that pops up in “2nd Medium Refraction Indices.” That’s the index of gelatin. Write the value here: ________.

2. Experiment with lots of different angles suggested by your team members. Write the values and results in your guide. How do the results compare?

- Compare their result with other teams. Since everyone is testing the same type of gelatin, everyone should have a similar answer.
- You will work with glass lenses in later meetings. Glass has a refractive index of about 1.5. Based on that number, does light bend more when traveling between air and glass, or air and gelatin?

Write your answer below:

______________________
______________________
______________________
______________________
______________________

Ahmed Kirmani, a finalist for the 2013 Lemelson-MIT Student Prize, created a new 3-D camera while at MIT as a PhD candidate in electrical engineering and computer science. Ahmed’s special camera helps track the position of your hands so that you can interact with your computer more easily. It’s like a gaming system that tracks the human body, but it’s more accurate and much cheaper. Learn more: http://lemelson.mit.edu/winners/ahmed-kirmani
Review

1. Refraction is the most fundamental principle for a camera. Cameras need to bend light to get an image. Most lenses are curved. That helps them change the angle of refraction over their surface to bend light toward the middle. The next meeting will be about how lenses bend light toward a focal point in the middle.

2. Teams will be given glass lenses to incorporate into a lens prototype in the next meetings. Teams’ devices will display an image and will allow a camera phone to capture an image. The specific kind of lens will be up to you. But first you will be asked to do some thinking about the type of user who needs a new camera invention.

One of the most persistent inventors in the history of cameras was Edwin Land (1909–1991), who dreamed up the Polaroid™ instant camera. The famous device developed a picture seconds after you snapped it. Land had the insight to design a system with all the chemicals needed to develop the image right under the surface of a special paper film. The instant camera was first invented in the 1940’s, but instant cameras sold by the Polaroid Company were most popular in the 60’s, 70’s, and 80’s. Learn more: http://www.biography.com/people/edwin-land-9372429#polaroid
Super Lens
Meeting 3: Sketch & Design

INVENTOR’S TOOLKIT

Minds-on
• Understand camera users’ needs
• Understand ray diagrams

Hands-on
• Cut with a utility knife
• Work with cardboard

Procedure
• Camera Users and Their Equipment
• Sketch a Camera Invention
• Cardboard Cutting Safety Rules and Tips
• Cardboard Cutting Demonstration
• Observe Light Rays Through a Lens
• The Science of Light
• Create a Lens Mount
• Review
• Self-Assessment

KEY TERMS

Aesthetic (adj): Relating to the visual or artistic appeal of something.

Diverging lens (n): A lens that spreads out light rays, also called a concave lens. The shape has a round part that is thicker on the outer edges. It curves in like a “cave.”

Function (v): To meet a specific use or need correctly.

Focal point (n): The focal point in a converging lens is the point in space where parallel light rays meet after passing through the lens. For instance, if you use a magnifying glass in sunlight, the focal point is where the light coming through the glass burns a hole in a piece of paper.

Hinge (n): A type of joint that moves and connects objects.

Optics (n): Optics in science is the study of the behavior of light; in photography, this science is applied to glass lenses and other mechanisms that control light in a camera.

Prototype (n): The very first version of a product idea, created with rough and improvised materials to make sure it functions.
Camera Users and Their Equipment

1. Read below the information that follows about camera users and their needs.
2. Consider the following prompts that you’ll discuss in your teams:
   - What real-world problem was the inventor of each camera trying to solve?
   - What research did the inventor use to get information? What kind of scientific research? What type of user research?
   - Are there other designs you have seen that are different from these camera designs? Describe them.

Camera users come from all ages and backgrounds. Some want to shoot pictures as part of their work, and some snap pictures of friends for fun. Many of these users, however, are interested in cameras that can take better-looking pictures from farther away. For example, if you can take pictures of friends from far away, you can shoot an image of them playing sports, performing, or enjoying other activities. And if you can take pictures of wild animals from a distance, you’ll get shots even when you can’t—or really don’t want to—get too close.

Camera lenses that can view subjects from far away use **zoom** lenses. These lenses are like little telescopes—they bring a distant object closer to your eye and the camera’s image sensor. Whether a camera can do this depends on the camera’s **optics**.

**Credit: Noushad PT**

**KEY TERMS (CONT.)**

- **Ray diagram (n):** A diagram that shows light as lines to explain the action of a lens or camera.
- **Zoom (adj):** Zoom lenses on a camera can view subjects from far away. These lenses are like little telescopes—they bring a distant object closer to your eye and the camera’s image sensor.
Super Lens
Meeting 3: Sketch & Design

Camera User: Nature Photographer

Kind of camera: Full-featured professional camera
Intended use: Photographing fast-moving subjects at a long distance
Type of lens: User needs to zoom close up from far away—a telephoto lens
Environment: Dusty and sometimes wet
Size: Large
Weight: 2 to 3 pounds
Image quality: Very high
Ruggedness: Made to withstand bumps and jolts
Portability: Moveable but heavy
Ease of use: Great user control over images, not easy to use

Credit: Babak

Camera User: Fashion Photographer

Kind of camera: Studio camera
Intended use: Indoor use, connected to a computer at all times
Type of lens: User needs to capture people close up, so a wide-angle lens
Environment: Clean and dry
Size: Very large
Weight: 3 to 4 pounds
Image quality: Highest available anywhere
Ruggedness: Delicate
Portability: Not portable, except in a large suitcase
Ease of use: Great user control over images, not easy to use
Camera User: Blogger

Kind of camera: Compact camera
Intended use: Kept in a pocket or purse, used to document news or social events
Type of lens: User needs to take a variety of pictures by zooming in and out—a normal lens
Environment: Dusty and sometimes wet
Size: A few inches across
Weight: Less than half a pound
Image quality: Average quality, appropriate for web uploads
Ruggedness: Delicate but made to withstand some bumps. Water resistant, not waterproof
Portability: Compact and portable when protected in a bag
Ease of use: Made for capturing quick images in chaotic environments; few user controls, very easy to use

Camera User: Parent or Caregiver

Kind of camera: Compact wireless video camera
Intended use: Placed in a distant room in the house, the camera relays a low-quality video image
Type of lens: User needs a good view from close up, so a normal lens
Environment: Clean and dry
Size: Two inches wide
Weight: 6 oz
Image quality: Low quality, color; enough for checking child’s safety
Ruggedness: Made to withstand bumps and jolts
Portability: Easy to transport but not made for travel
Ease of use: Very easy to use; no user controls over image
Super Lens
Meeting 3: Sketch & Design

Camera User: Professional Snowboarder or Skier

Kind of camera: GoPro™ camera
Intended use: Capturing distinctive images of athletes and their teammates for use on promotional materials and social media
Type of lens: User needs to squeeze a lot of people or scenery into a single photo—a wide-angle lens
Environment: Dirty and wet
Size: A few inches wide
Weight: 2.9 oz
Image quality: Medium quality, enough for display online
Ruggedness: Made to withstand bumps, jolts, and water
Portability: Very portable
Ease of use: Easy to use; some user controls over image for artistic effects

Sketch a Camera Invention

1. Think about and discuss unmet needs for camera users today in areas such as medicine, law enforcement, hobbies, or sports. Try to imagine two professional or amateur camera users.

2. Discuss with your team a camera that would solve key problems for these users, then have a team member sketch your camera invention. Remember that an idea will likely evolve over the next several meetings as your team builds its camera. This brainstorm session is only the first step.
<table>
<thead>
<tr>
<th>Kind of Camera:</th>
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<tr>
<td>Intended Use:</td>
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<tr>
<td>Specifications</td>
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<tr>
<td>Size:</td>
<td>Weight:</td>
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<td>Type of Lens:</td>
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<th>Usage:</th>
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|
3. Fill in the following information on the sketch, estimating size and weight:

Kind of camera:
Intended use:
Type of lens:
Environment:
Size:
Weight:
Image quality:
Ruggedness:
Ease of use:

4. Present your camera designs to the whole group before the hands-on activity that involves cutting cardboard.

Cardboard Cutting Safety Rules and Tips

1. Review these additional safety rules for cutting cardboard:

   • Always wear safety glasses.
   • Always cut on top of masonite board in order to protect tabletops.
   • Hold the utility knife with your thumb near the front and your pinky near the back, as if you were holding a spatula to make breakfast.
   • Stand up to get better leverage on your work when cutting.
   • Keep your other hand on the material to stabilize it, but above and away from where you’re going to cut. Don’t cut toward your hand.
   • Make a shallow cut first along the line, slowly and easily.
   • Make a few more cuts along the same line until you cut all the way through.
   • Don’t cut all the way through the cardboard if you want to bend the board into a shape.
   • Cut against a ruler for precision.
   • Close the blade when not in use.

2. Watch the video below, Cutting Cardboard (4:13), from MIT’s Design Online, a resource for design and prototyping. Review the safety notes with students frequently throughout the meeting.
Cardboard Cutting Demonstration

1. Cutting cardboard safely is critical. The utility knife is razor-sharp and can cause serious injury. Your teacher will demonstrate what you saw in the video and at the same time create a simple double laser-pointer holder for the next activity. This device will hold two laser pointers, turn both of them on at once, and keep the beams parallel.

   • Measure a small, 2 x 6 inch piece of cardboard with the yardstick, marking with a pencil. Connect the lines using the straight edge of the yardstick.

   • Cut out the rectangle using the utility knife.
   • Hold the utility knife with your thumb near the front and your pinky near the back, as if you were holding a spatula to make breakfast.
   • Stand up to get better leverage on your work when cutting.
   • Keep your other hand on the material to stabilize it, but above and away from where you’re going to cut. Don’t cut toward your hand.
   • Make multiple shallow cuts first along the lines, slowly and easily.
   • Make a “partial cut” across the middle of the small cardboard rectangle by cutting through the top paper layer so you can bend the cardboard in half.
Note: Students used black foam core in the photos in this unit.

• Snap the rectangle in half so that it operates like a hinge.

• Tape two laser pointers to the cardboard so that their power buttons are both pointing up and their beams are parallel.

• Sandwich the laser pointers together between the cardboard layers and press firmly. They should both turn both on at the same time and shine parallel beams.
Super Lens
Meeting 3: Sketch & Design

Observe Light Rays Through a Lens

1. One team member will hold the double-laser pointer during the experiment.

2. One student is in charge of holding a converging lens in the air.

3. Another student is in charge of holding the Haze Spray.

4. Darken the room.

5. The first student should sit or stand, holding the laser pointer a few inches away from the team member holding the lens so the two parallel beams can travel through the lens. The other student should spray some Haze in the area between the pointer and the lens to make the beams visible.

(Left) Simple double-laser device for examining lenses. (Right) Device folded over with laser “on” switches pressed at the same time.

Attempt to send both beams into the lens in a parallel manner.
6. Observe the place behind the lens where the light beams cross. This is the place where the lens puts these beams in focus.

Laser beams should cross after passing through the converging lens. Use Haze Spray to clearly see the beams.

7. Turn the lights back on. Your educator will collect the laser pointers. Complete the following questions:

• What did you observe about the beams?
  
  ___________________________________
  ___________________________________

• Why do you think this is?
  
  ___________________________________
  ___________________________________

8. The lens you experimented with is a converging lens, also called convex. Such lenses bring together rays of light onto a spot or focus them behind the lens. These lenses are used for cameras like the one in your phone, as well as telescopes, eyeglasses, and movie projectors.

A converging lens brings parallel light waves together at the **focal point**.

In contrast to converging lenses, diverging lenses—also called concave lenses—are thinner in the middle. Such lenses spread out light rays as they pass through the lens.

**Diverging lenses** are hardly ever used alone in cameras and telescopes, but assist converging lenses in adjusting an image, removing distortion, and improving color representation.
The Science of Light

1. Watch the optics video from Kahn Academy, Learn Convex Lenses (9:22). It uses ray diagrams to show the path of light through various lenses.

2. Experiment with the online interactive demonstration from PBS LearningMedia, Geometric Optics. It allows you to see the relationship between an object, a lens’s focal point, the material’s refractive index, and the real image formed. Observe how the values change according to the density of the lens’s medium. Modern cameras sometimes use plastic, silicone, and other lens materials with various refractive indexes. The most common lens material is glass.

3. Use the instructions and the example below to draw a picture of how light rays travel through a lens:
   - First, draw a lens in the middle of your drawing area. Next, draw a stick figure and light rays going from the stick figure to the lens. Then draw an eyeball on the other side. This is called a ray diagram.

Create a Lens Mount

1. Read the information that follows on smartphone lenses and instructions on how to make lens mounts.

2. Your educator will review with your class the smartphone lens information and lens mount instructions.

3. Make sure you have watched the video instructions about how to cut the material and have reviewed the safety instructions before cutting the cardboard.
4. Do you have questions? Review safety notes frequently throughout the meeting.

Many inventors are looking for better ways to create lenses for smartphones. Currently, smartphone cameras cannot zoom in on subjects far away. Many have a digital zoom function, but this uses software to make the picture bigger at the expense of quality. Some companies are finding ways to create an external lens for smartphone cameras. Other companies, such as DynaOptics, are looking for ways to squeeze zoom lenses inside thin smartphones.

You will build a prototype with a lens for a smartphone camera in the next two meetings. Your finished lenses will be a lot bigger than commercially available products, but they are intended as prototypes. You will need to choose a lens and build a housing.

A professional-quality zoom lens from Beastgrip™ attaches to a smartphone to capture images. Credit: Lubchyk Yakymiv

You will build a prototype with a lens for a smartphone camera in the next two meetings. Your finished lenses will be a lot bigger than commercially available products, but they are intended as prototypes. You will need to choose a lens and build a housing.

Examples of the prototypes students will build over the next two meetings.
• Pick one of the biconvex lenses at random. At a later point, you may want to swap this lens for one from another team, but teams will do the research to find out the lens characteristics for now.
• Note that each lens has a different thickness and diameter. This is because each lens has a different focal length. Lenses with a short focal length make objects look farther away in a photo, but show a wider view of the world. This is called a wide-angle lens. Lenses with a long focal length display objects closer up, but show a narrower view of the world with fewer objects. This is called a standard, or telephoto, lens.

The lens you choose—and its focal length—will determine the size of the team’s prototype and the kind of images it produces.

• First, you and your teammates will use your cardboard cutting skills by mounting a lens onto a cardboard square, then taping it securely.

• One team member will use the utility knife to cut a 4 x 4 inch square of cardboard. Be sure they protect the table by cutting on a masonite board. You don’t have to be exact or even use the straight edge for this step. This is the rough, proof-of-concept stage. As inventors, you are interested in exploring **function**, not **aesthetics**.

• Trace around the center of the 4 x 4 inch square.
• Cut a rough square around the perimeter of the tracing. Take your time to avoid cutting your fingers.

• Pop out the interior of the square and place the lens inside.

• Place a couple of pieces of masking tape along the top and bottom edges of the lens and press along the lens edge to make sure they stick.
Super Lens
Meeting 3: Sketch & Design

- Flip the lens mount over and place eight or more pieces of tape around the lens, pressing along the edges to get a secure, light-tight fit.
- This mounted lens will be used in the next meeting. Initial your team’s mounted lens with a pencil.

Review

1. Talk to friends and family about their camera needs before the next meeting. What functions are lacking from their cameras and smartphone cameras? ________________________________
   ____________________________________________
   ____________________________________________

2. The activities you are doing are building skills toward creating your own inventions. Keep thinking about new lens and camera features you’d like to invent.

3. What were your impressions of cutting foam core? Do you have questions or concerns about this skill?
Manu Prakash, a 2008 Lemelson-MIT Student Prize Finalist, wanted to find an inexpensive way for people to see very small biology samples. His recent invention, Foldscope, is a $1 microscope made from paper that folds together like origami.

Microscopes work by placing two converging lenses together—one to magnify the object like a magnifying glass, the other to magnify that image. The Foldscope has a very small, pea-shaped lens that allows samples to be enlarged 2,000 times. Prakash, now a professor at Stanford, is working to distribute the device to rural areas to help improve global health.

INVENTOR PROFILE

Manu Prakash, a 2008 Lemelson-MIT Student Prize Finalist, wanted to find an inexpensive way for people to see very small biology samples. His recent invention, Foldscope, is a $1 microscope made from paper that folds together like origami.

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Biological samples examined under the Foldscope, a microscope that assembles in 10 minutes. How were images captured?

Credit: Foldscope Team

Foldscope inventor Manu Prakash. Credit: Foldscope Team
KEY TERMS

Focal length (n): The distance between the lens and the focal point is called the focal length.

Focus (v): To manipulate the light rays originating from an object so that they come together at a point. When this has been done, an image usually looks sharp.

Image plane (n): The area behind the lens where the image is in focus. You focus a camera by adjusting it so that the image plane will be on the image sensor. That way, the sensor captures a sharp image.

Super Lens
Meeting 4: Test Components

INVENTOR’S TOOLKIT

Hands-on
- Examine images
- Build a test setup

Minds-on
- Calculate a focal length
- Find the image plane

Procedure
- Look through Your Team’s Lens
- Calculate the Focal Length of Your Lens
- Review
- Self-Assessment
Look Through Your Team’s Lens

Take a few minutes to look at different objects with your team’s lens. Look at things close up like a magnifying glass. Look at distant objects with the lens close to the eye. Look at distant objects with the lens at arm’s length. Record what you see in your guides.

Calculate the Focal Length of Your Lens

The goal of this meeting is to calculate the focal length of a lens. Like any researcher, you will need to run tests to find out what lens prototype meets the need of the intended user. This will help your team know how big to build the housing for your prototype in the next meeting. You will find the focal length of the lens by using the thin lens equation, shown below:

**Focal Length Equation:**

\[
\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}
\]

- \(d_o\) = distance of object from lens
- \(d_i\) = distance of image from lens
- \(f\) = focal length of the lens

Credit: Eurah Ko

- Tape the yardstick to a table so that it stands on one edge.
Super Lens
Meeting 4: Test Components

- Attach one clothes pin to the lens mount that your team made. Use additional clothes pins clipped together to adjust the height of the lens mount in relation to the light source.

- Place the lens mount at the end of the yardstick at 0 inches.

- Attach the LED light to a moveable object like a chair or coat rack and place it about a foot from the lens.

Credit: Eurah Ko
• Use the second yardstick to determine the distance, in inches, between the lens and the LED light. The light is the object in this test, and the measurement is the variable \(d_o\) in the thin lens equation. Write the distance in inches here: \________.

• Take a piece of vellum paper and hold it over the yardstick so that the lens mount is between the light source and the vellum paper. Move the paper various distances from the lens until the image is in focus.

• A clear image that is in focus will form on the paper at a certain distance. Block some of the LED lights with tape. What impact does this have on the image? How was the “upside down U” image created in the image to the right? The top LEDs were blocked by blue tape and the light traveling through the convex lens produces an inverted image!

STUDENT AND EDUCATOR NOTE

Focal Length Equation:

\[
\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}
\]

\(d_o\) = distance of object from lens
\(d_i\) = distance of image from lens
\(f\) = focal length of the lens
Super Lens
Meeting 4: Test Components

- This is the **image plane** where the image is in focus. Write down the distance in inches from the yardstick here: __________. Now you have variable \( D_i \) — the distance between the lens and the image plane.

- Now that you know \( D_o \) and \( D_i \), you have all the variables to solve the equation. Use a calculator—and your algebra skills—to find \( f \). Mark this number down here: __________. You will need this number to build the housing for the prototype in the next meeting.

Sample Solution *(not to scale)*

\[
\frac{1}{f} = \frac{1}{D_o} + \frac{1}{D_i}
\]

\[
\frac{1}{f} = \frac{1}{60.8\text{in}} + \frac{1}{4.4\text{in}}
\]

\[
\frac{1}{f} = \frac{1}{60.8} \left( \frac{4.4}{4.4} \right) + \frac{1}{4.4} \left( \frac{-60.8}{60.8} \right) \text{ Make common denominator}
\]

\[
\frac{1}{f} = \frac{4.4}{267.5} + \frac{60.8}{267.5}
\]

\[
\frac{1}{f} = \frac{65.2}{267.5} \quad \text{Add numerators}
\]

\[
f = \frac{267.5}{65.2} \quad \text{Flip}
\]

\[
f = 4.1\text{in} \quad \text{Use calculator}
\]
Review

1. Can you recall the focal length of your lens? You should know that the thin lenses—the ones with long focal lengths—will be able to zoom in on subjects far away. The thick ones—the ones with short focal lengths—are good for portraits of people and social gatherings in which the photographer wants to put a lot into a single picture.

2. Are you satisfied with the lenses for your prototype? Each team will need one lens for building the housing for their prototype in the next meeting.

3. Discuss your lens choice with your teammates. Trade with another team if you want to.

INVENTOR PROFILE

A big environmental problem with smartphones is that when a new camera or screen comes out, users often want to buy a whole new phone and throw away the old one. Around 70 million phones end up in landfills every year, with only 50 million recycled.

Paul Eremenko, an MIT graduate who worked at Google, helped invent a phone that can be improved with new components. Things like stereo speakers and cameras snap in and out like LEGO® bricks.
KEY TERMS

Perpendicular (n): A straight line at a 90° angle to another line.

Super Lens
Meeting 5: Build a Lens

INVENTOR’S TOOLKIT

Hands-on
• Measure carefully
• Cut with a utility knife
• Use a hot glue gun

Minds-on
• Find the image plane

Procedure
• Introduction to Product Development
• Build the Housing
• Cardboard Cutting Safety Rules and Tips
• Measure Cardboard for a Housing
• Cut Cardboard
• Glue the Box
• Build the Outer Lens Box
• Finish Your Lens and Test It
• Discuss
• Review
• Self-Assessment
Introduction to Product Development

1. You discussed various camera users and their needs during the last meeting. Look over the modern camera designs that follow and discuss with your team members the possible needs that product developers may have explored that led to their designs.

2. Next, fill in the blank for each user need and make your best guesses about the technical features of each product. Circle the appropriate multiple-choice items, based on previous meetings and your basic understanding of cameras.

3. How should you move from your drawings to a first prototype, sometimes known as the alpha prototype? You will be creating a working prototype lens using the calculations you made in the last meeting.

The secret to good product development is frequently discussing ideas and options among team members and with the intended user.

The teams will eventually have a lens prototype that will work with a camera phone.

The development process many inventors go through to create a product starts with a brainstorming stage, where inventors identify a common problem and think of various ways to address it with a new idea. They do research with users and may imagine their own difficulties with existing products.
Next, there’s a prototyping stage, in which inventors build a working version of the idea to show how it will function. The project may not look pretty in this stage, but everything will work to show users how it could solve their problem.

**iPhone Camera**

What problem does this camera solve? ________________________

What size is the camera?
Small:___________ Medium:___________ Large:___________

What image quality do you think the camera produces?
Low:___________ Medium:___________ High:___________

What do you think the focal length of the camera is?
Short:___________ Medium:___________ Long:___________
(⅛") (½") (2")

How many optics on the camera do you think the user can adjust?
None:___________ Some:___________ A lot:___________
What problem does this camera solve? __________________________
__________________________________________________________

What size is the camera?
Small:____________  Medium:____________  Large:____________

What quality do you think the camera produces?
Low:_____________  Medium:_____________  High:____________

What do you think the focal length of the camera is?
Short:____________ (⅛”)
Medium:____________ (½”)
Long:______________ (2”)

How many optics on the camera do you think the user can adjust?
None:____________
Some:____________
A lot:____________

Canon F-1 Camera

Soon after the first image sensor was invented, an engineer working for the camera and film company, Kodak, got a fun assignment from his boss. The boss asked Steven Sasson, “What can you do with a CCD sensor?” Sasson tinkered in Kodak’s lab and invented a camera—the first digital camera. All cameras before that used chemicals and film to produce a picture. In 1975, Sasson and his company were awarded a U.S. patent for the invention.
Super Lens
Meeting 5: Build a Lens

Build the Housing

1. Review the safety instructions and watch the video if you have not already done so.

2. Review the instructions below on constructing the lens prototype.

3. Work with your team to start building your lens prototype.

Cardboard Cutting Safety Rules and Tips

- Always wear safety glasses.
- Always cut on top of masonite board in order to protect tabletops.
- Hold the utility knife with your thumb near the front and your pinky near the back, as if you were holding a spatula to make breakfast.
- When cutting, stand up to get better leverage on your work.
- Keep your other hand on the material to stabilize it, but above and away from where you’re going to cut. Don’t cut toward your hand.
- Make a shallow cut first along the line, slowly and easily.
- Make a few more cuts along the same line until you cut all the way through.
- Don’t cut all the way through the cardboard if you want to bend the board into a shape.
- Cut against a ruler for precision.
- Close the blade when not in use.

4. Review all the instructions on constructing a housing for the lens prototype before cutting cardboard.
Super Lens
Meeting 5: Build a Lens

Measure Cardboard for a Housing

You will begin by measuring pieces of cardboard for a housing in preparation for making the prototype. When the housing is done, it may not look great—nothing like a store-bought product—but it will focus images and allow you to experiment with the design.

The three components of the lens prototype

- Start with the lens you intend to use. Refer to the focal length calculations you made in Meeting 4. Write down the focal length for that lens from the calculation made in Meeting 4: _________. Subtract ½ inch: _________.

- The focal length minus the ½ inch will be the depth of the inner housing box. Take that number and measure along the edge of the cardboard using the yardstick. Put a pencil mark at the measured distance.
• Make the same measurement on the other edge of the cardboard. Use the yardstick’s edge to draw a pencil line to make a long rectangle.

• Now measure every 7 inches along the bottom edge to create four smaller rectangles in the cardboard.

• Finally, find a space on the cardboard outside the rectangle to make a single square that measures 7 x 7 inches.
Super Lens
Meeting 5: Build a Lens

Cut Cardboard

1. Cut along the lines you drew to cut out the long rectangular piece containing the four small rectangles. Do not to cut the small rectangles! These pieces only need to be partially cut on the surface. Others need to be cut all the way through. The single 7 x 7 inch square can be cut out with the utility knife.

- This 7 x 7 inch square will be used to make a lens holder.

2. Use the utility knife to make shallow cuts into the cardboard for the smaller rectangles within the long rectangle. Cut through the top paper and part way through the cardboard so you can bend these into corners in the next step.
3. Next, cut a small circle, 3½ inches in diameter, in the single 7 x 7 inch square, using the directions in the steps that follow.

4. Find the center of the square so you will know where to cut the hole. Line up the yardstick at opposite corners and draw a line, then line up the two other corners and draw a line **perpendicular** to the first one. The center is where the two lines cross.

5. Measure the lens to get the rough size of the hole you will cut: the opening doesn’t have to be exact. For a 3½ inch hole, for example, you’ll measure 1¾ inches in all four directions from the center of the square. If your lens requires a larger or smaller hole, you will adjust this measurement.

6. Draw a circle in pencil to connect the marks.
7. Do your best to cut out a round circle using the utility knife. It doesn’t have to be a perfect circle! Make sure you keep your hands away from the knife blade as you cut. Put the piece with the hole in it to the side while you glue the box sides together.

Glue the Box

Review these instructions on gluing the box sides together, using a hot glue gun safely.

SAFETY

Find a spot on a desk or table where you can create a safe station for the hot glue gun. This will be a place near an electrical outlet where no one will trip over the cord. It will also be a place where no one will accidently put their hand on the nozzle.

The hottest part of the glue gun is the nozzle. It can cause a serious burn if touched. Be very careful to keep your hands away from the nozzle.

Hot glue can injure you. Be careful not to get hot glue on your skin, but if you do, pull it away immediately. It will hurt but is unlikely to leave a blister.

Unplug the hot glue gun as soon as you are done. Leaving it plugged in could create a fire hazard.

Put a piece of paper down under the hot glue gun. These devices tend to leak the sticky glue when they are plugged in but not in use.
1. Plug in the glue gun and wait 3 to 5 minutes for the glue to get hot.

2. Gently snap along the partially-cut lines of your cardboard pieces. A small amount of pressure on the opposite side from the scored lines will create a crease and a sharp edge held together by paper backing.

3. Because you snapped the edges (and didn’t separate them), the panels should hold together while you bend them. Form the panels into a box shape. Do not worry if one or more of the sides separated completely—you can glue them together in the next steps. You should have a cardboard box held together by one layer of paper.

4. Hot glue the final two edges together so you have a rectangular box with no top or bottom. Hold it in place and let the glue set (cool and harden) for a couple of minutes.
Super Lens
Meeting 5: Build a Lens

• Stand the box on its end. Take the last square with the hole in it and glue around all four edges, then quickly place it on top of the box. Hold it to let the glue set for a couple of minutes.
Build the Outer Lens Box

1. Review the instructions for making the outer box of the prototype:

The next stage is to make the part of the housing that will slide back and forth over the inner box you just made. This will help focus the lens. The outer box is similar to the inner box, except that it will have no top or bottom and it will be just a little bit bigger.

• Measure a long rectangle just like before, using the same dimensions for the focal length of the lens minus ½ inch. Measure along the edge of the cardboard using the yardstick, and mark in pencil at the measured distance.

• Make the same measurement on the other edge of the cardboard. Using the yardstick, you should draw a line in pencil to make a long rectangle.

• Measure every 7¼ inches along the long rectangle to create four smaller rectangles in the cardboard. Adding the ¼ inch along each side will make the outer box just large enough to slide back and forth over the inner lens box.
Super Lens
Meeting 5: Build a Lens

• Cut out the long rectangular piece containing the four small rectangles. Do not cut the small rectangles! Cut carefully and slowly along the lines, according to the cardboard cutting directions.

• Use the utility knife to make shallow cuts into the cardboard for the smaller rectangles within the long rectangle. Cut through the top paper and partway through the cardboard so you can bend these into corners in the next step.

• Gently snap along the scored lines of the cardboard piece. A small amount of pressure on the opposite side from the scored lines will create four sides held together by paper backing.

• The panels should hold together because you snapped the edges and didn’t separate them. Form the panels into a box shape. Do not worry if one or more of the sides separate completely—you can glue them together in the next steps. You should now have a cardboard box held together by one layer of paper.

The partial cuts on your foam core will snap but stay held together with one layer of paper. They will move back and forth like hinges in the paper.
• Hold the outer box together with your fingers and test whether it fits smoothly over the inner one. If it does, hot-glue the two open edges so you have a rectangular box with no top or bottom.

To snap the partial cuts, apply a little pressure on the back of the cardboard.

A box shape can be created using the partial cuts.

• If the two boxes don’t fit, separate them and flip them around in different ways to see if you can get them to fit. If the two boxes still don’t fit, you may have to do some cutting and adjusting. Remember, this is how inventors learn. The prototype may experience problems, but that’s part of the design process. Troubleshoot to see if you can solve the problem.

• Use the utility knife to carefully trim any overhanging edges or extra hot glue off the inner box and try again.

• Place masking tape along all the (cooled) hot-glued edges of both boxes to prevent light leakage.

Front View, Inner Box

Glue

Outer box

Inner box
Super Lens
Meeting 5: Build a Lens

Finish Your Lens and Test It

1. Review the instructions on how to finish the prototypes:

   • Tape the lens mount you made in Meeting 4 over the front hole of the inner box.

   • The final step is to add a screen made from paper vellum that will allow you to see the images. First, you'll make the frame using the 7 x 7 inch square of cardboard.

   • Test the square to see if it fits in the outer box.
   • Measure ¾ inch from each corner of the square in both directions and mark with a pencil.
   • Connect the lines with the yardstick to form an inner square.
• Cut out the inner square, being careful not to cut into the outer square because you will need the cardboard’s strength to hold the vellum paper.

![Cut out inner square](image1)

• Cut a piece of vellum big enough to cover the square, and tape it in place on all four edges. Try to stretch the vellum taut so that it doesn’t have waves or wrinkles.

![Cut vellum](image2)

• Push the screen down into the outer box about halfway, and tape it in place, straight up and down in the box. Then aim the lens at a window, friends, or any bright scene and move the outer box back and forth until the scene comes into focus on the vellum. You can find another object around the room at a different distance from the lens and focus on that. You may have to adjust the focus by moving the outer box differently for near objects versus far ones.

![Push screen](image3)
Super Lens
Meeting 5: Build a Lens

Discuss

1. Discuss what you saw on your screen with your team members when you are done testing your lens.
   • What’s in focus?

2. Draw a ray diagram on the page at the end of this meeting. Your diagram should illustrate what’s happening inside the lens housing.

A completed housing, ready to hold a lens.
A student tests his lens prototype. **Credit: Bob Parks**

A distant image viewed on the vellum screen. **Credit: Bob Parks**

A close-up object viewed on the screen. **Credit: Bob Parks**
Super Lens
Meeting 5: Build a Lens

Review

1. There will be time at the beginning of the next meeting to finish the lens prototypes.

2. What do you think of the images created by your prototype so far? Why are the images upside down? Recall ray diagrams in Meeting 4. Converging lenses bend light rays as they cross at the focal point. This inverts the image.

HIGH SCHOOL CONNECTION

The 2012 S.S. Seward Institute InvenTeam in Florida, New York, used a large Fresnel lens to concentrate rays from the sun and heat water to a boil under pressure—specifically, to 249 degrees Fahrenheit at 15 p.s.i. pressure for 15 minutes—to sterilize medical instruments. Learn more here: http://lemelson.mit.edu/teams/54-6

Members of the high school team that invented the solar-powered steam autoclave. Credit: Lemelson-MIT
Draw a Ray Diagram
<table>
<thead>
<tr>
<th>Questions</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Look at the image. Does the lens have a good zoom capability? Can you tell just by looking at the image? Is this how it was intended?</td>
<td></td>
</tr>
<tr>
<td>Does the image show that the lens was the best option for the subject depicted? Could there have been a better choice of lens?</td>
<td></td>
</tr>
<tr>
<td>Does the lens create a shallow depth of field or a wide one?</td>
<td></td>
</tr>
<tr>
<td>Is the image too dark or too light? If it is too dark or too light, does it nevertheless have a pleasing effect on the eye?</td>
<td></td>
</tr>
<tr>
<td>What other subjects would this lens be good for? What other industries? Health care, security, news gathering, consumer electronics? Explain.</td>
<td></td>
</tr>
<tr>
<td>What are some recommendations for improvement?</td>
<td></td>
</tr>
<tr>
<td>How would you design the rest of the smartphone to go with the lens? What materials would you use?</td>
<td></td>
</tr>
</tbody>
</table>
Super Lens
Meeting 6: Take Digital Photos

Procedure
- Build a Smartphone Mount for the Lens Prototype
- Choose Photography Subjects and Take Pictures
- Print Conventional Images
- Saul Griffith on Inventing
- Introduction to Purposeful and Unique Inventions
- Brainstorm Invention Ideas
- Review
- Self-Assessment

KEY TERMS

Capture (n): The process of creating and storing images to use later.

Critique (n): A thorough analysis or review of something.

Empathy (n): The ability to understand and share the feelings of another.

Pitch (v): To present your idea to a potential funder or supporter. This process often involves getting them interested in your idea and wanting to help you develop it into a product.
An example of an image with a shallow depth of field
Credit: By Pseudopanax at English Wikipedia (Own work) [Public domain], via Wikimedia Commons
Build a Smartphone Mount for the Lens Prototype

You will capture the images that appear through your prototype lens by using a smartphone camera. You can then can print the image and save the file to use later. Your first step is to build a mount for the housing and attach it to a smartphone.

1. Cut a 7 3/8" x 7 3/8" square of cardboard. Wear safety glasses and follow all safety rules. Cut the cardboard in several shallow cuts, slowly and easily along a straight edge.

2. Find the center of the square by drawing two intersecting lines. Line up the yardstick at opposite corners and draw a line across the square, then line up the other two corners and draw a line perpendicular to the first one. The center of the square is where the two lines cross.
3. You will cut a hole in the center of the cardboard. Measure ½ inch in all four directions from the center of the square.
4. Draw a box connecting the marks, then carefully cut out the box in the center of the square using a utility knife.

5. This square piece of cardboard with a small square center cutout will be attached to the outside of the prototype housing using a piece of masking tape. The tape will act like a hinge and allow you to flip the smartphone mount out of the way to view the image on the vellum.

6. You should use your smartphone to properly align the smartphone in the mount’s center hole. Find a clear image on the vellum viewing screen with the lens you made. Turn your smartphone on and move its lens over the mount hole until your phone displays the image that is displayed on the vellum viewing screen.

7. Tape the smartphone to the mount once you have the image on the smartphone’s viewing screen. The mounted smartphone should resemble the image of outer housing on the left of the picture below.

Apple has applied for a patent to put optical zoom lenses in its smartphones. Some day iPhones may have two lenses—one for taking pictures of nearby objects and one for far-away objects.
Super Lens
Meeting 6: Take Digital Photos

Choose Photography Subjects and Take Pictures

1. Look for photo opportunities around the classroom. Subjects should be static (non-moving) and fairly well lit. The subject can be a person or object. Choose subjects near and far away for variety.

Keep in mind the following:
• Look at the results and adjust the lens prototype to improve the focus.
• Consider taking a few pictures of the team or the whole group.
• Photo too blurry? Adjust the focus by sliding the boxes back and forth slightly.
• Photo too dark? Find a more brightly lit scene.

Print Conventional Images

1. Review the instructions on how to print images on a color or black-and-white printer.

• Upload photos from the prototype’s mounted smartphone to a computer.

• Print your favorite images using the printer in the classroom.

A sample image captured by a lens prototype and a smartphone.
Credit: Bob Parks
2. Create a photo gallery by hanging photos around the room. Your team should create a caption for its printed image. Photos and captions are often the first things that readers look at online and in print. Displayed photos should include the written captions. Captions may include:

- Names of people from left to right in the photograph. Make sure names are spelled correctly.
- Date and location of when and where the photo was taken.
- A sentence about why the photo was taken. The sentence should be written in present tense.
- In addition to the caption, credit should be given to the photographer(s).

3. You will critique all of the photos and offer constructive feedback on the technical quality of the photos. The table on the next page can guide your critiques. Critique your team’s photo first and discuss it with your teammates.

**HISTORY**

George Eastman (1854–1932) founded what today is the Eastman Kodak Company. Eastman was mostly self-educated as a kid and started working at an early age to support his family after the death of his father. In 1884, Eastman patented the first film in a roll. Roll film benefited users because they were able to take pictures one after another. In addition, Eastman's invention of film rolls later sparked the idea of movie film.

The 1888 patent for the first Kodak camera to use film in rolls.

*Credit: USPTO*
### Super Lens
**Meeting 6: Take Digital Photos**

<table>
<thead>
<tr>
<th>Technical Quality</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the lens have a good zoom capability? Can you tell just by looking at the image? Is this what the photographer intended?</td>
<td></td>
</tr>
<tr>
<td>Does the image show that the lens was the best option for the subject in the photo? Was there a better choice of lens?</td>
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<td>Is the image too dark or too light?</td>
<td></td>
</tr>
<tr>
<td>What other subject would this lens be good for? Why?</td>
<td></td>
</tr>
<tr>
<td>What other industry (health care, security, news gathering, consumer electronics, etc.) would this lens be good for?</td>
<td></td>
</tr>
<tr>
<td>What are some recommended technical improvements?</td>
<td></td>
</tr>
</tbody>
</table>

Photo taken by: __________________________________________

4. Each team should next critique other teams’ photographs. Use the table to record your critiques.

5. Have a spokesperson from your team critique all of the photographs. Offering constructive feedback to others is very important. It is a skill to provide and receive feedback effectively.
Saul Griffith on Inventing

Growing up, Lemelson-MIT Student Prize winner Saul Griffith says he was an average student but loved to tinker with things. He created a helicopter powered by fireworks and a grappling hook based on Batman’s. Today, Griffith holds more than 50 patents. He is the leader of an invention company called Otherlab in San Francisco, where he and 70 engineers develop ideas for all kinds of inventions, from T-shirts that adapt to keep you cool to bionic suits that could one day protect people from injury. The two biggest customers of Otherlab are the U.S. Department of Energy and the Department of Defense.

Griffith's workshop is fitted out with expensive machines such as a water-jet cutter that can slice through steel, a five-axis router that can make a part from a solid block of metal, and a giant inflatable elephant that can walk. The place is often chaotic, with more than five dogs running around during the week.

When Griffith was an MIT student getting his PhD, he invented a low-cost device that helps a person with vision problems get an accurate prescription for glasses. He built it after a trip to Kenya during which a government official told him that 25 percent of students couldn’t read because they didn’t have proper corrective lenses. The community couldn’t afford expensive testing equipment to get students their prescriptions.
Super Lens
Meeting 6: Take Digital Photos

Griffith responded to that need by creating a lens-molding machine for glasses. A test pair of flexible lenses is filled with transparent oil, and a technician makes the lenses fatter or thinner depending on how much oil is squeezed into the lens. This way, the technician can carefully dial in the person’s prescription and manufacture an inexpensive pair of finished glasses in the machine. (See an additional photo at the MIT Museum website or watch a demonstration of the device (8:01 and 10:24) in Griffith’s TED talk.) Griffith won the Lemelson-MIT Student Prize for invention in 2004 based on this invention.

Saul’s advice for future inventors and engineers:

Learn from others: “While you’re young, ask to take a tour of every manufacturing plant you can think of—whether they’re making bread, toothpaste, or solar cells. People love to open their businesses to students.”

Join a team of inventors: “The best way to work is to bring a dream into reality collectively.”

Build lighter: “Try using soft, lightweight materials to create your inventions. A lot of products today are heavier, stiffer, more massive and more expensive than they need to be. For instance, a palm tree’s trunk is flexible enough to survive a hurricane.”

Think bigger: “It’s getting easier to make your ideas real. Big changes are happening in transportation, manufacturing, and health care. There’s no reason not to pitch your exciting visions for the future in a more entrepreneurial way.”
Go deeper: “Understand the mechanics and mathematics underlying the problems you’re interested in solving; that way, you can change the game when you get the big idea.”

Consider:
• If you could ask Saul one question pertaining to his work, what would it be?
• What classes in high school or college might help prepare you to be an inventor?
• Would you be interested in becoming an optical engineer? Why?
• Is there a company that you would like to work for? Why?

Introduction to Purposeful and Unique Inventions

Sit back and reflect on the new toolkit of skills you have acquired in this unit. You have learned the different ways in which invention is centered on empathy and fulfilling people’s needs. You have new minds-on skills such as working in teams and understanding the design process and the science of light. You also have gained hands-on skills such as conducting tests on lenses, building prototypes, and capturing images.

• Ask yourself, “How could I use my new skills to solve a real problem?” Your challenge is to select a person or group of people with a need and apply your skills to invent a solution.

Conceptualize a project using optics in some way. Your ideas have the possibility of becoming InvenTeams projects in future years!

Before you decide what to invent, you must research a real need and determine who you will be helping. You can think locally, regionally, nationally, or even internationally. If you choose to look internationally, research the needs of a particular country or region to develop a product that may be useful. Perhaps your school already has a partnership with a “sister city” in another country.

For additional information on problems/needs in other countries, explore the World Bank website.
Super Lens
Meeting 6: Take Digital Photos

Brainstorm Invention Ideas

1. Work in pairs to develop and track invention ideas. Use the skills and information you’ve learned about lenses and cameras to complete the challenge.
   • How can you create a low-cost or easy-to-use camera?

   ______________________________________________________
   ______________________________________________________

   • Can you think of a meaningful way to use lenses other than in cameras?

   ______________________________________________________
   ______________________________________________________

   • How can the lens-building process be used to create something new?

   ______________________________________________________
   ______________________________________________________

2. First think about who your invention will help, and then start to brainstorm ideas.

3. The most successful brainstorms are the ones in which all ideas—even wacky ones—are proposed and all ideas are accepted. You never know when a wacky idea will inspire a great invention!

4. Share your ideas with the group.

Review

1. At the next meeting, you and your group will continue brainstorming invention ideas you may want to try out. Think about your invention between now and the next meeting. Talk with friends and family members about invention ideas.
2. Camera optics are not only for visual images—they can be used for such things as body tracking for gaming, health care devices, and assisting people with visual handicaps.

INVENTOR PROFILE

Achuta Kadambi witnessed arguably the most significant change in photography while growing up in Silicon Valley: the transition from film to digital cameras. He is now a PhD student at the MIT Media Lab and hopes to contribute to another revolution: redefining the camera to exceed the capabilities of the human eye. Achuta’s aim is to build “superhuman visual systems,” which have been realized in more than a dozen of his U.S. patent filings. His inventions include ultrafast optics to film light in motion (“Nanophotography”) and an imaging system that relates nearly imperceptible rotations of light with 3D models of the world.
Super Lens
Meeting 7: Invention Extension

**INVENTOR’S TOOLKIT**

- **Hands-on**
- **Minds-on**
  - Develop a plan for an invention to solve a real problem.

**Procedure**

- Read About Real-World User Needs
- Brainstorm Invention Ideas
- Discuss as a Class
- Make a Plan
- Self-Assessment
Read About Real-World User Needs

1. Review the examples of purposeful inventions on these pages, and discuss the questions at the end as a class.

The following three purposeful inventions are based on real user needs. The inventors thought of specific ways a person would rely on them in the real world.

All three examples are a little different from the usual camera purpose. Cameras aren’t always just for taking snapshots: cameras can come in many shapes and sizes. They serve many purposes. There are surprising applications for cameras—not to mention engineering challenges in getting the optics right.

**Example 1**

Users wearing the EyeRing on their finger simply point it at the world to learn more about it. The EyeRing can help who are visually impaired people to read tags in a clothing store, count money, or decipher street signs. The camera snaps a picture of what's in front of it and then sends the information to a smartphone, which analyzes the image and gives the user an audio description.

**HIGH SCHOOL CONNECTION**

Today, when a hiker is lost in the woods, it often takes hundreds of people walking through dangerous terrain to find them. The InvenTeam at University High School in Irvine, California, believes it has a better idea, involving an infrared camera and a quadcopter. The team figured out a way to navigate the drone with GPS directions. When the aircraft is over the hiker's general area, it starts shooting infrared images—pictures that show warm objects, such as the lost hiker’s body.
Super Lens
Meeting 7: Invention Extension

The inventor, Pattie Maes, is a professor at MIT’s Media Lab. She often uses cameras to give computers new ways of sensing the world. Watch MIT’s video about the project on the project’s website, EyeRing (3:15), to understand how the ring works.

Example 2

Thomas Nutman, a doctor and researcher who works in Africa, was looking for a low-cost gadget that could help count the number of Loa loa worms in a person’s bloodstream. These nasty worms get into people’s blood through horsefly bites. Many people in Sub-Saharan Africa are infected, and an accurate count of the number of worms in a blood sample tells doctors whether it’s safe to prescribe medicine.

Dan Fletcher, an engineer at the University of California, Berkeley, decided to help. He invented a cheap microscope that uses an iPhone. He designed optics to work with the smartphone’s camera, helping to magnify the worms 350 times. Recently, a test of 33 patients in the African country of Cameroon accurately identified the worms by using the device. For a demonstration, watch Smartphone Video Microscope Automates Detection of Parasites in Blood (:30).
Example 3

Imagine brushing your teeth and getting help from the dentist all at once. That’s the idea behind an invention by students in MIT’s Camera Culture group, a research team that finds new ways of using cameras and computers. This team realized that many people in the developing world don’t get regular visits to the dentist. The camera photographs a panoramic view of a person’s teeth using a polarized lens (the same glass used in many sunglasses) to eliminate the glare from sparkling teeth! Then, if a computer analysis suspects cavities, it alerts a dentist right away. MIT’s Camera Culture group invented the tooth-cam on a visit to Mumbai, India.

Discuss as a Class

• Can you think of a camera that a person could wear? What unique task would it do?
• What other things should smartphones keep track of visually? Would it help to give a smartphone “eyes” to see dangerous situations or people’s facial expressions?
Super Lens
Meeting 7: Invention Extension

Inventors of the toothbrush cam testing and improving the device. 
*Credit: MIT*

- What about the physical design of digital cameras and smartphones? Will smartphones always have a flat and rectangular shape, like a chocolate bar? Why not other shapes, such as a ring or a necklace? What do you think a phone will look like in ten years?

**Brainstorm Invention Ideas**

1. Complete the following activity to brainstorm invention ideas:
   - Do some of your own brainstorming in your guide, using the SCAMPER technique.
   - SCAMPER is a process for coming up with solutions. It is based on the notion that many new things are modifications of something that already exists. Each letter in the acronym represents a different way to look at a problem:
     - **S** = Substitute (Playing basketball with a softball.)
     - **C** = Combine (Toothbrush combined with a pencil to create a new product.)
     - **A** = Adapt (How would you eat spaghetti without a utensil?)
     - **M** = Magnify (How would your chair function if the legs were wider and longer?)
     - **P** = Put to Other Uses (Could your fork be used as a comb?)
     - **E** = Eliminate (Could you play tennis without a racket?)
     - **R** = Rearrange or Reverse (What if shoelaces were placed on the bottom and not the top?)
     (Remember that all ideas are good ones. Record all your ideas in your guide!)

2. Have students check out other InvenTeam projects on the *Lemelson-MIT Program* website.
Make a Plan

1. Work with your teams on the following activity to create a potential InvenTeams grant. Discuss ideas and streamline those ideas. You can select one idea as a team to take to the next step.

2. This is not a project that will be completed from start to finish in the JV InvenTeams meetings. It can be planned and completed outside of meeting time.

3. One good way to gather ideas is using Google Patent Search.

4. Ask yourselves the following questions to make sure you are on target:
   • Is the product offering something useful and unique?
   • Are you excited and motivated to develop your idea?
   • What new tool and/or material skills would you need to learn?
   • If the product meets a local need, would a community group, municipality, university, or company want to get involved with the project?
   • Who will benefit from the invention? Is there a clearly identified user? Use the invention worksheet in your guide to document and sketch the idea. This is a version of what InvenTeams use in their project proposals.

5. Share your ideas with the class in a culminating celebration of your work. Apply for an InvenTeam grant if you want to continue this work!
Invention Challenge Brainstorm

For this brainstorm, it's important that you get ALL of your ideas down, especially the wacky ones! You never know when a wacky idea will turn into a great invention.

WHO will you help?

WHAT will you invent?
What problem do you want to solve?

S = Substitute
(Playing basketball with a softball.)

C = Combine
(Toothbrush combined with a pencil to create a new product.)

A = Adapt
(How would you eat your spaghetti without a utensil?)

M = Magnify
(How would your chair function if the legs were wider and longer?)

P = Put to Other Uses
(Could your fork be used as a comb?)

E = Eliminate
(Could you play tennis without a racket?)

R = Rearrange (or Reverse)
(What if shoelaces were placed on the bottom and not the top?)
Invention Worksheet

Our JV InvenTeam members are:

The product we are inventing is: _______________________________ to _______________________________.

(.short description of what it does)

______________________________________________________________.

It is useful for ___________________ because _____________________.

(the user) (description of the need or problem)

It is unique because ____________________________________________

(description of how it’s different from other solutions)

______________________________________________________________.

It functions by _________________________________________________

(description of how it works)

______________________________________________________________.

The tools we need are:

__________________  __________________  ________________  ________________

The materials we need are:

__________________  __________________  ________________  ________________

__________________  __________________  ________________  ________________

__________________  __________________  ________________  ________________

__________________  __________________  ________________  ________________

The estimated total cost of our invention will be: $ __________________
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