Description
This one-hour lesson helps students explore the properties of magnification in x-ray imaging by taking the role of a radiologist to magnify the image of a breast calcification by 5x its actual size. Students will take measurements as they move the “calcification” to various distances from the light source, graph their data and compare their findings to three proposed equations for magnification to identify the correct equation.

Context
This lesson was designed as a one-time session for students coming from different high schools to Stanford University’s Splash weekend of classes taught by Stanford undergraduate and graduate students. Participants should have experience plotting points on a graph, plugging in values for variables in an equation, and using a ruler. Familiarity with geometry of similar triangles is helpful.

Learning Objectives

- Students will review the basic setup of projection radiography used in taking mammograms.
- Students will learn that magnification in mammography increases as the patient (object) gets closer to the source of x-ray photons (x-ray tube).
- Students will validate the magnification formula \( M=\frac{SI}{SO} \), where \( M \) is the magnification factor, \( SI \) is the source-image distance, and \( SO \) is the source-object distance.
- Students will test alternative functions against data they have collected to identify the true formula.
- Students will have the opportunity to derive the magnification formula from first principles using the concept of similar triangles.

Materials (per pair of students)

- Two copies of the worksheet (click here for the PDF)
- One light source such as an LED pen flashlight or cell phone camera light. The smaller and brighter the light source, the clearer the shadow will be. Example models include the Coast G10 Max Beam Optic Flashlight and the Coast Cutlery TT75331CP Clip-On LED Light.
- Large manila file folder (or other upright surface to capture shadows)
- A 1cm square of paper adhered to a short (2-4 cm) stand to hold it in place. The stand can be fashioned from two halves of a popsicle stick and glue, such as from a glue gun.
- Centimeter-scale ruler
- Two pencils - these need not be sharp. Please handle sharp pencils with care.

Stands with precisely measured 1 cm square calcifications, made from pre-colored halves of popsicle sticks connected with a glue gun, and construction paper pasted with glue stick. The stands are taped to a cardboard strip for convenient storage and transportation.
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<tr>
<th>Time</th>
<th>Activity</th>
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<tr>
<td>3 min</td>
<td>Open with an introduction and icebreaker. If students the class already know each other, skip or insert another warm-up to spark interest and activate prior knowledge relevant to the task. Introduce your name and background as the instructor. Ask participants to introduce themselves to the people at their table and find as many things as they can that they all have in common. After one to two minutes, call the group together and invite tables to volunteer share what they found in common.</td>
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<th>10 min</th>
<th>Provide your students background information on radiography</th>
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<td>Give your students the “X-ray Vision” worksheet. Have them read it over independently or ask volunteers to read it aloud if you have struggling readers in your class. Use the questions below as jumping-off points to build and assess comprehension of background information. Encourage students to use their handout to answer the questions.</td>
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<td>Question: What does x-ray mean?</td>
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<td>Learning Point: There are at least two meanings of the term x-ray: 1) a type of electromagnetic (EM) radiation. Other types of photons (EM radiation) include radio waves, visible light, infrared (heat lamps), and ultraviolet (the component of sunlight which causes tanning and skin cancer). Order these types of EM radiation on the energy spectrum, from lowest energy to highest: radio waves, microwaves, infrared, visible (ROYGBIV), ultraviolet, x-rays, gamma rays. Discuss other types of photons students are familiar with in everyday life (infrared, visible light, ultraviolet); 2) a radiograph, the image that is made by detecting the x-rays that pass through an object. Radiographs are made by first generating x-ray photons in the direction of an object (the body). Some pass through the object and are detected on the “image”, but others are absorbed and do not pass through. The source of x-rays is called “Source”, the body is called “Object” and the image detector is called “Image”. The distance between the Source and the Object is called Source-Object Distance, or SOD. The distance between the Source and the Image is called the Source-Image Distance, or SID.</td>
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<td>Question: Which lets more x-rays pass through: bone or lung?</td>
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<td>Learning Point: The thicker and denser the body part – and the higher the atomic number of the element that makes up the body part – the fewer x-rays that will pass through that body part. Bone is denser than lung, because bone is solid and lung is mostly filled with gaseous air.</td>
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<td>Question: Look at the chest radiograph. Does the image look darker or lighter in the places where more x-rays hit the image detector?</td>
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<td>Learning Point: The image detector tallies how many x-rays hit it at different parts of the detector. The number of x-rays detected is translated to grey scale pixels. By convention, places in the image where more x-rays passed through, like the lungs, are represented by darker pixels. Places in the image where fewer x-rays passed through, like the bones, are represented by lighter pixels.</td>
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Give instructions for the guided exploration segment

Read the Clinical Challenge on the handout to students. In pairs, they will experiment using a flashlight to represent the x-ray source, a 1cm paper square to represent the calcification (object), and a manila folder standing up to visualize the resulting shadow (image).

1. Collect data: Record the fixed values of the Source-Image Distance and actual height of the object (just the paper square, which should be 1 cm in height, not the height of the square from the table surface). Line up the flashlight and folder at the designated positions marked on the worksheet. Move the object to at least four points along the ruler in between the source and image. For each point, students should record the source-object distance, the size of the shadow (image height), the magnification – image height divided by actual height (1cm) – and the blurriness of the shadow.
2. Plot their data on the graph and draw the curve.
3. Figure out how many centimeters from the x-ray source to place the breast in order to get the calcification to look 5 times as big as it actually is.
4. Fill in values for the three equations, graph them and decide which equation best matches the data collected. In other words, which is the correct equation for determining magnification? The correct equation will be \( M = \frac{\text{SID}}{\text{SOD}} \). Note that SID is fixed in this experiment - we’re only varying SOD, similar to the clinical scenario of moving the patient's breast relative to the source.
5. When finished, consider discussion questions in the grey box.

Before beginning work, make sure students can answer the following comprehension questions:

- What is the “Source” in the real clinical situation and for the purposes of our experiment?
- What is the “Object” in the clinical case and in our experiment?
- What is the “Image” in radiology and in our experiment?
- What are SID and SOD in radiology and in our experiment?
- What are you trying to figure out?

Oversee the guided exploration segment

Circulate and guide students. Make sure they understand how to set up the materials, take the measurements, and interpret the terms. Their data will not match any equation perfectly. Encourage students to think about various sources of error that would lead to discrepancies between data and equations. Examples include error from ruler-based measurements, and blurry images from diffuse light sources. About 15 minutes from the start of this segment, pause the class and ask groups who figured out how to achieve a magnification of 5 to share their results with the class. Give any other guidance necessary to make the end of work time productive and successful for all.
**Lead the closing discussion**

1. What is your recommendation for where to position the breast to get it to look five times as big in the picture?
2. What did you find out about the Source-Object Distance and magnification?
   a. The image gets bigger as you move the object closer to the light (or x-ray) source.
   b. The image also gets blurrier as you move the object closer to the light source.
   c. Magnification increases more rapidly as the object gets closer to the source.
3. Which of the proposed equations best matched your data?
   a. The formula \( M = \frac{S_{ID}}{S_{OD}} \) correctly describes the relationship.
4. What might have caused differences between the data and what we would predict from the equation?
   a. It's hard to accurately measure a shadow on a flimsy folder.
   b. It's hard to accurately measure a blurry image, which is caused by a diffuse light source. The wider the light source, the more points of light are casting shadows, and each one casts a slightly different shadow, which we see as blurriness.

**Total time: 1 hour**

**Extensions**

1. Compare the patient’s image on the handout with images of benign and malignant calcifications to determine whether it looks suspicious.
2. Explore how density and thickness affect how much light passes through using materials of different levels of transparency (eg. clear plastic, layers of tissue paper).
3. Develop a geometric explanation of why blur exists in projection radiography.

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**Where does blurriness come from in x-ray images?**

A realistic source of photons, like a flashlight or an x-ray tube is more like *multiple* point sources than a single point source.
4. Develop a geometric explanation of why blur increases as the object gets closer to the light source.

Why does blurriness increase with magnification?

- **object**
- **blurry image**
- **multiple point sources**

Source-image distance (SID) has been increased with a fixed source-object distance (SOD), which increases magnification, \( M = \frac{\text{SID}}{\text{SOD}} \).

The same diverging x-rays that allow for magnification also spread out the multiple shadows, increasing blurriness.

5. Derive the \( M = \frac{\text{SID}}{\text{SOD}} \) formula for magnification using the concept of similar triangles.

Using similar triangles to derive the magnification formula

Assume a single point source.

Identify the similar triangles

Object height

Image height

SOD

SID

Triangles in blue and orange are similar, so we know that \( \frac{\text{SID}}{\text{SOD}} = \text{image height} / \text{object height} \). Recall that magnification \( M = \text{image height} / \text{object height} \). Thus, we have that \( M = \frac{\text{SID}}{\text{SOD}} \), which is the magnification formula.