BioMedTech:

Imaging the Human Body

TechXcite: Discover Engineering

Pratt School of Engineering
Duke University
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Module Overview
This TechXcite: Discover Engineering module introduces youth to ways in which engineers use science and math to create technology capable of seeing inside the human body. Youth will explore the concept of density and learn how X-rays, CT scans and ultrasound technologies work. In the end, they will build a model of an ultrasound machine.

**Activity 1:** Youth create images using sunlight in a manner analogous to an X-ray machine to learn how a basic X-ray machine works.

**Activity 2:** Youth test the density of objects relative to water to gain a basic understanding of how X-rays use density to create images.

**Activity 3:** Youth learn how computed tomography (CT) scans use math to integrate many different X-ray images into a single, detailed three-dimensional image.

**Activity 4:** Youth complete a simple worksheet to learn what the minimum sampling interval must be to detect objects and how it relates to ultrasound and submarines.

**Activity 5:** Youth work in groups to create a device to allow them to map a surface in a manner analogous to ultrasound.

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TechXcite Program
TechXcite is a partnership between the Pratt School of Engineering at Duke University, the National 4-H Council/4-H Afterschool and North Carolina 4-H.

The program is directed by Drs. Gary Ybarra (PI) and Paul Klenk (Co-PI). Beginning in 2001, they co-created the successful Techtronics afterschool engineering program at Rogers-Herr Middle School and Lowes Grove Middle School in Durham, N.C. The TechXcite: Discover Engineering curriculum is building on this work by creating engineering learning modules in seven theme areas for use in afterschool programs nationwide. Together they have created an engaging, substantive, experiential and inquiry-based curriculum in engineering, technology and applied science for 4-H-supported middle school youth in afterschool programs across the nation. We hope to encourage youth in both rural and urban settings to pursue careers in engineering and technology.

If your program is interested in adopting any of the TechXcite: Discover Engineering learning modules, please contact us at techxcite@duke.edu.

Online Support
The TechXcite Web site (techxcite.pratt.duke.edu) contains additional material to help you implement this module. There are videos to guide you through facilitating the activities with students. You can download copies of the Instructor's Guide and Youth Handouts. You'll also find a list of sources for any materials you'll need. Finally, there are links to additional resources.

E-Mail and Phone Support
If you have questions about any of the material in this curriculum, please do not hesitate to ask. The Duke team is available to support you if you have questions about implementing the modules. Please contact our staff at techxcite@duke.edu. You can also call us anytime by calling the program manager at the phone number listed on the Contact Us page on our website - http://techxcite.pratt.duke.edu/contact/index.php.
Using this Guide
The first portion of this handbook is the Instructor’s Guide for all of the activities in the module. It includes this introductory section and also the Instructor’s Guide for each activity. This introduction contains general information about the TechXcite curriculum, what to expect in each activity’s Instructor’s Guide and background on tools you will be using.

The Instructor’s Guide for each activity follows the same format. Below is what you can expect to find in each section. At the beginning, you will find basic information about the module. This includes:

- Time Required
- Materials
- Group Size – This is the suggested number of students per group.
- Youth Handouts – These will need to be copied.
- Instructor Preparation – This includes what you need to do before the activity and approximately how much time it will take you.
- Learning Objectives
- Vocabulary

Introduction, Procedure and Activity Closure
Three sections form the body of the activity: Introduction, Procedure and Activity Closure. The Introduction and Activity Closure sections are scripted. You may read these sections verbatim to students. Instructions that are not to be read to students, as well as answers to questions, are in brackets/italics. The Procedure section is not scripted. It contains step-by-step instructions for facilitating the activity with a group of students.

Cleanup
This section appears in activities in which cleaning up in a particular way will help reassemble the kit or prepare for the next activity. Following these instructions will keep the kit in proper order.

Assessment
This section tells you how to assess whether or not students understood the material presented to them in the activity. These assessments are generally based on students’ answers to questions asked during the Activity Closure section.
Activity 1: The Sun as an X-ray Machine

Time Required: 45 minutes
Group Size: 2-3

Materials List
Each group needs:
- Sunprint® photo paper
- Leaves or flowers (Not provided. See Instructor Preparation.)

To share with entire class:
- Sunprint® kit developing supplies
- Small aluminum pan

Youth Handouts:
- None

Instructor Preparation (15 minutes)
- Select a sunny, outdoor area where you can place photo paper to develop for 5 to 10 minutes.
- Make sure you have a water source to develop the prints.
- Gather a few leaves or flowers. Choose materials that have varying thickness or composition.

Learning Objectives
After this activity, students should be able to:
- Explain that X-rays are like light.
- Explain that X-rays and light are both electromagnetic waves.
- Explain how an X-ray image is made.

Vocabulary
<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electromagnetic radiation (EM)</td>
<td>Waves of a specific frequency and wavelength.</td>
</tr>
<tr>
<td>X-ray</td>
<td>A form of electromagnetic radiation.</td>
</tr>
</tbody>
</table>

Introduction
Today we are going to learn about X-ray images. Have you ever had an X-ray to detect a cavity or broken bone? What did the doctor do to make the image? What did the image look like?

An X-ray machine uses film, like a traditional camera does, to capture an image of something inside your body. The machine generates X-rays that are directed through the body and onto a piece of film on the opposite side. For dental X-rays, the film is
placed inside the mouth. Hard parts of the body, such as bones and teeth, absorb X-rays and so they appear as white spots on the image. X-rays pass more easily through soft tissue such as muscles and organs. The shadowy or dark parts of an X-ray image represent soft tissue or air spaces. Fractures, cracks and holes also show up as dark spots, allowing doctors to detect broken bones or tooth cavities.

An X-ray is a type of electromagnetic radiation just like light, but unlike light, it is invisible to us. Today we are going to produce an image of an object using sunlight, similar to the way a doctor makes an X-ray. Because visible light doesn't pass through thick or dense objects, we are going to use leaves and flower parts, which are much thinner. We will be using special light-sensitive paper that acts like film.

**Procedure**

1. Take students outside, then hand out the Sunprint® paper and objects to each group.
2. Instruct students to place the paper on the ground and place their object on top of it.
3. Wait 5-10 minutes for the prints to develop. (The paper will continue to react until it is rinsed in water.)
4. Rinse the prints in the pan. (If you are going to do this inside, block light from the paper while taking it indoors.)
5. Give students an opportunity to examine one another’s prints and identify some of the objects. Ask them to notice which objects were reproduced more clearly than others and to consider why this happened.

**Activity Closure**

Can any of you explain what happened when the objects were placed on the paper?

In places where light could easily pass through the object, the paper was darker because it was more exposed. Where part of an object blocked sunlight from reaching the paper, the image remained lighter. Light can shine through some objects more easily than others. Your photosensitive paper captured the light that penetrated your object, just as X-ray film captures X-rays. However, X-rays can pass through thicker objects than sunlight can. X-rays can easily pass through skin, but harder substances, like bones, prevent X-rays from reaching the film.

A German physicist named Wilhelm Röntgen discovered X-rays accidentally while working with cathode rays (now called electron beams) in his laboratory in 1895. He noticed an image cast on a fluorescent projection screen far beyond what could have been reached by the cathode rays. He experimented by placing several different objects, including a deck of cards, a book and a wooden box with metal weights inside, between the cathode ray tube and the screen. Röntgen observed that X-rays passed through some material more readily than others. When he placed a lead pipe between
the rays and screen, he noticed that his finger bones appeared in shadow. He later took an X-ray of his wife’s hand that produced a picture of her bones and wedding ring (shown here) on a photographic plate. Röntgen called the rays “X” radiation because this type of radiation was unknown. The term became X-rays, for short, and the name stuck. Röntgen’s groundbreaking discovery led to many advances in the field of medicine.

Assessment
Ask students to draw a picture representing someone having an arm X-ray, including the X-ray machine. Students’ drawings should include the following: the part of the equipment that generates the X-rays, a representation of the X-rays being sent through the arm, the arm itself and the film on the other side.
Activity 2: Density of Materials

Time Required: 30 minutes
Group Size: 2

Materials List
Each group needs:
- 5/8-inch (diameter) wooden ball
- 2½-inch (diameter) wooden ball
- 5/8-inch (diameter) marble
- 5/8-inch (diameter) steel ball
- 16-ounce plastic cup

Youth Handouts:
- None

Instructor Preparation (5 minutes)
- Fill each group’s cup with water, about halfway. Make sure the 2½-inch diameter wooden ball has space to float in the water.

Learning Objectives
After this activity, students should be able to:
- Explain that some materials have a greater density than others.
- Explain that density is mass divided by volume.

Vocabulary

<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>Mass per unit of volume. The formula for obtaining this is mass divided by unit volume.</td>
</tr>
</tbody>
</table>

Introduction
Today we are going to explore the concept of density. In the previous activity, you learned how we use sunlight or X-rays to take a picture. Sunlight can penetrate only thin objects. X-rays, on the other hand, can penetrate thicker objects. The density of an object determines how much of the X-ray radiation it absorbs and how much it allows through. Density determines essentially how translucent an object is.

Procedure
1. Place students in pairs.
2. Give each pair the four different balls: 1 marble, 2 sizes of wooden balls, 1 steel ball.
3. Instruct them to spend a few minutes discussing the differences between the objects.
   a. They may notice superficial differences in texture or other properties.
   b. They will also likely notice that three of the objects have the same volume but not the same mass.
c. They should recognize that wood is lightest for the same volume, but the larger wooden sphere is heaviest.

4. Give each group a cup filled with water.

5. Ask students which objects they think will float or sink when placed in water, and ask them to test their predictions by putting the balls and marbles in their cups of water.

6. Once students have had time to experiment, ask them what they think causes an object to float or sink. [They will likely have a number of answers. Encourage them to test their ideas.]

Activity Closure
What did you find out about the objects that did or did not float?
[Provide the opportunity for students to discuss what they observed during the experiment.]

You probably discovered that knowing an object’s mass or volume is not enough to predict whether it will sink or float. The small wooden ball was the lightest object and the large wooden ball was the heaviest, yet both of them floated. The small wooden ball had the same volume as the steel ball and the marble, yet it floated and they sank. To predict whether an object will sink or float, you need to know not only its volume, but also its mass.

Density is the property that determines whether an object will sink or float. The object will float in water if its density is less than the density of the water. The density of a material is independent of its mass or volume. Who knows how to calculate density? [Density equals mass divided by volume.]

Assessment
To assess understanding of density, bring in other objects and ask students to determine which one is denser using whatever method they can come up with.
Activity 3: CT Scans: Improving X-Ray Imaging

Time Required: 45 minutes
Group Size: 3-4

Materials List
Each group needs:
- Deck of cards

Youth Handouts:
- “What is Computed Tomography (CT)?”

Instructor Preparation (None)

Learning Objectives
After this activity, students should be able to:
- Explain that computed tomography (CT) scans use X-rays.
- Explain that computed tomography (CT) scans compile information from X-ray images taken from multiple angles to form a three-dimensional image.
- Explain that computed tomography (CT) and computed axial tomography (CAT) are two terms for the same medical imaging technology.

Vocabulary

<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back projection</td>
<td>A method of combining data from multiple beams of X-rays to create a picture of the inside of the body.</td>
</tr>
<tr>
<td>Computed tomography (CT)</td>
<td>A form of X-ray imaging that produces a three-dimensional image.</td>
</tr>
</tbody>
</table>

Introduction

In Activity 2, we looked at how a standard X-ray image is created. Today we’re going to explore another medical technology that uses X-rays to capture a more detailed view of the body. It is called computed tomography or CT. Has anyone ever heard of a CAT scan? What do you think it is? A CAT scan, also called a CT scan, is a form of X-ray imaging. But instead of generating two-dimensional images like X-rays do, CT provides a three-dimensional view.

A CT scanner takes X-ray images from many different angles. A computer then mathematically processes the information to produce a three-dimensional image. Essentially, CT depicts the density of something inside the body. Objects that are dense have a large mass-to-volume ratio, and X-rays will not easily pass through them. On a CT image, a dense object will appear as dark spots. Today you’re going to explore how CT scans work.
Look at the Activity 3 handout. You will see three images of a human head. What differences do you notice?

No. 1, below, is a standard X-ray. The object, in this case the head, was exposed to a beam of light, similar to the object in the Sunprint© activity we did. More dense or less dense areas are shown, but it was only possible to take the X-ray from one angle. The images shown in No. 2 were created using multiple X-ray angles to create a CT scan. These slices were created using math to combine information from regular X-ray scans taken from multiple angles. These slices were used to create the three-dimensional picture of the inside of the head, shown in No. 3. Creating this three-dimensional image makes it possible for a doctor to examine the brain for density differences at any point.

Why is this important? Tumors are often more dense than surrounding tissue. A dense spot on the scan could be a tumor and may need to be examined by a doctor.

1) **Standard X-ray image** – human head

2) **CT slice images** – human head

3) **3D CT Image** – Slices from the previous set of images (No. 2) can be stacked together to create a three-dimensional model of a head.
How does a CT work? Page 1 of your handout gives a simple overview of the basics behind CT.

**Procedure**

1. Place students in groups of 3 or 4.
2. Give each group a handout and a deck of cards.
3. While students are completing the instructions on the handout, circulate to assist.
4. When students lay their playing cards on the table, they will create a grid that looks like the picture below. Each card represents the X-ray intensity measured at that point. Students should then use the back projection technique of adding the two cards together to determine the density at a given point. They can record this in the grid on their handouts. The density in the upper left would be 5+8=13.
Activity Closure
How does CT differ from a standard X-ray?
[CT captures more details by combining multiple X-ray images to form a three-dimensional picture.]

What are some advantages of CT over a normal X-ray?
[Greater detail; nothing blocks the view of things behind it (for example, in a chest X-ray the bones can block the image of the lung behind it).]

Assessment
Examine students’ completed handouts to see if they added the values correctly. The Activity Closure question assesses their understanding of CT versus X-ray.
Activity 4: Ultrasound and Submarines

Time Required: 30 minutes
Group Size: 2

Materials List
Youth Handouts:
- “What is Computed Tomography (CT)”

Instructor Preparation (10 minutes)
- Choose an outdoor location where there is a large wall, such as the wall of a gymnasium. Obtain two small, thick blocks of wood that you can clap together to make a loud sound. You could also simply clap your hands. Stand 75-100 feet from the wall and make the sound. Do you hear the echo? In this way, you can sense the wall. You can use this exercise as an opening demonstration for this activity.

Learning Objectives
After this activity, students should be able to:
- Explain that echolocation is used to determine the distance of objects from an ultrasound sensor.
- Explain that to ensure that all objects are found, the space between samples taken must be the size of the smallest object to be sampled.

Vocabulary

<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echolocation</td>
<td>Determining the distance to an object using sound waves.</td>
</tr>
<tr>
<td>Frequency</td>
<td>Number of waves per second.</td>
</tr>
<tr>
<td>Resolution</td>
<td>Size of the smallest detectable space between two objects.</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>High-frequency sound waves that cannot be heard by the human ear (but can be heard by some animals such as dogs, bats and dolphins).</td>
</tr>
</tbody>
</table>
Introduction

In the last few activities, we examined medical imaging that uses X-ray radiation. The inside of the body may also be imaged using sound waves that are outside of the range of human hearing. This is called ultrasound. In this activity and the next, we will discuss how it works.

[Take students outside to the desired location and have everyone stand 75-100 feet from the wall. Clap two blocks of wood together or just clap your hands. You could also have a student yell.]

Do you hear an echo? That echo tells us that the wall is in that direction. If we wanted, we could also tell exactly how far away the wall is. For example, the speed of sound in air is 343 m/s (768 mph). Knowing that, we can measure the amount of time between clapping and hearing the clap and use that information to calculate how far away the wall is, using the echo. Another example is determining the distance to a lightning bolt. To tell how far away lightning is, you can count the seconds between when you see the lightning bolt and when you hear the thunder. It takes about 5 seconds for sound to travel 1 mile, so if it takes 5 seconds for the sound to reach you, you know the lightning is 1 mile away. The light reaches your eyes almost instantaneously because it travels about 186,000 miles per second, much faster than the speed of sound.

Is anyone familiar with the term echolocation? [Give students a chance to answer and explain what they think it means.] The word means exactly what it implies: using sound, specifically echoes, to find out where something is located. Sometimes an object is too far away to see, or the environment may be too dark or murky. Bats and dolphins use echolocation to find and catch prey. They emit a sound and then locate the object based on how long it takes the sound to bounce back to them. Clapping our hands and timing the echo off the wall is a form of echolocation. Ultrasound uses a similar technique on a much smaller scale to create images inside the body.

Ultrasound is used by submarines underwater to avoid collisions or find enemy ships. When a submarine wants to find an object, it transmits a sound wave and then listens with a special device to see if the sound wave is reflected back. By calculating how long it takes for the reflected wave to return, the people on the submarine can determine how far away the object is. If the submarine transmits a high-frequency pulse moving at 1,050 meters per second and receives the echo 1 second later, it knows that the second submarine is 525 meters away.

Procedure

1. Place students in pairs and distribute handouts.
2. Instruct them to examine the diagram of the submarine.
3. Give them these instructions: The submarine is at the surface and needs to survey a distance of 100 meters along the ocean floor. The submarine wants to know how many submarines underneath it are 5 meters long or longer. Help the submarine determine the number of objects below it.
Activity Closure
How far apart must your survey lines be to detect all the submarines in the field? [5 meters]

How does this number relate to the 5-meter minimum object size? [It is the same.]

To completely sample a field with objects that are X meters long, you must sample every X meters. This is a fundamental theory in engineering and is used in everything from cell phones to medical imaging equipment. The smallest distance detectable between objects is called resolution. On the submarine worksheet, the resolution was 10 meters when the submarine sampled every 5 meters.

Assessment
The questions in Activity Closure provide a quick method of checking knowledge gained.
Activity 5: Imaging with Sound

Time Required: 60 minutes
Group Size: 3

Materials List

Each group needs:
- Shoe box or other small box with lid
- Pair of wooden chopsticks
- Ruler
- One sheet of graph paper
- Corrugated cardboard (Not provided. See Instructor Preparation)
- Objects for bottom of “sea floor” (Not provided. See Instructor Preparation)

One per 2-3 groups:
- One package of markers
- Roll of masking tape (1/2” width)

To share with entire class:
- Glue stick
- Package of pipe cleaners
- Package of wooden craft sticks
- Scissors

Youth Handouts:
- “Imaging with Sound”

Instructor Preparation (10 minutes)

- Gather objects to represent the bottom of the sea floor for the terrain maps students will make. These can be cut-outs from boxes, foam bricks, soda bottles, shells, rocks, sand, wooden blocks, etc. They should fit inside the locator boxes that students will make; 2 to 5 inches is a good size estimate, though smaller or larger could work.
- Gather a few small, lightweight boxes with lids (shoe boxes, cake boxes, etc.). Students will use these to make their locator boxes.
- Find a few corrugated cardboard boxes or other rigid material. Cut out flat pieces that are the same size as the base of students’ locator boxes. Students will create their terrain maps on these pieces of cardboard (see handout).

Learning Objectives

After this activity, students should be able to:
- Explain that ultrasound uses sound waves to see images inside the body.
• Explain that ultrasound is often used to view a baby inside a woman who is pregnant.
• Explain that echolocation is used to determine the distance of objects from an ultrasound sensor.
• Explain that the space between samples taken must be the size of the smallest object to be sampled to ensure that all objects are found.

Introduction

Last time, we began exploring how ultrasound creates an image. In this activity, we will build our own model ultrasound devices and use them to create images.

Have you ever seen an ultrasound image of a baby before it has been born? It looks sort of like a blurry, black-and-white snapshot. Medical professionals can use ultrasonic sound waves to “take a picture” of the inside of the body. Ultrasonic sound waves are sound waves that cannot be heard by the human ear. To make an ultrasound image, a trained medical technician, or sonographer, places an ultrasound transmitter on the outside of the body. The device then transmits ultrasonic sound waves into the body and receives echoes back, like the way a submarine uses echolocation. The machine then uses the time elapsed between transmission and reception to determine the position of objects within the body.

Ultrasound determines not only where an object is, it also helps determine the object’s size and shape. Like a CT scan, ultrasound provides a three-dimensional view of the inside of the body, but unlike CT scans, sonograms can show an image instantaneously. Ultrasound can show an image of your heart while it is beating.

Radiation from X-rays may be harmful in large quantities. This would only affect you if you had X-rays every day for a year, but it could hurt newborn babies, who are especially susceptible to radiation. Ultrasound does not use harmful radiation, so there is no limit to the number of images a doctor may safely take, and it can be used with newborn babies.

Ultrasound returns a signal at the boundary between different types of tissue just like the wall of the building returned a sound. These boundaries are what produce the image.

Medical ultrasound devices work much like the submarine that surveyed the field in the previous activity. These medical devices send out ultrasound waves and measure how long it takes to sense or “hear” a return signal. Instead of scanning at intervals like a submarine, medical ultrasound devices can survey a wide area at once. This is because they use many sensors rather than just one.

Today you are going to design your own echolocator ultrasound device. It will work much like a submarine’s sonar system.
Procedure

1. Tell students they are to make a locator that moves along the long edge of a box and takes depth readings at specified positions. They must be able to tell precisely where the locator is taking readings and how deep it goes. The following pictures show two different measuring techniques.
   a. The first example uses a ruler, which fits into slots cut in the top of the box, to take depth readings at specific intervals.
   b. The second example takes depth readings using a chopstick with inch measurements marked on it.
Both locator boxes use a grid on top to determine depth at multiple locations. Notice in the first example, one ruler goes into the box about 5 inches before it stops. That is the depth of the box. The other ruler only goes in 3 ½ inches because it has encountered an object. This is the same information an echolocator or ultrasound gets from sensing an echo.
2. Instruct students to design their locator and 3D object map on a sheet of paper before handing out the supplies. An example of a map is shown on the Activity 5 handout.

3. Distribute supplies and ask students to build their locators.

4. When everyone’s locator is completed, tell the groups to exchange maps with another group. One group is to put its terrain map into another group’s locator box, as shown below. The opposing group’s members should not look while this is happening. Once the lid is closed, they should use the locator device to create a map of what is in the box and draw it on graph paper.
5. Allow about 20 minutes for each group to locate and identify another’s objects.

**Activity Closure**
1. What were some problems you encountered while trying to interpret the terrain map provided by the other group? Were the problems related to sampling frequency or something about your designs?
2. How might you improve your locator design if you had more supplies or unlimited resources?
3. What was the smallest feature detectable in the 3D map you created?

**Assessment**
Determine whether students were able to explain that the smallest detectable object was the distance between measurements.
Activity 3: What is Computed Tomography (CT)?

Computed Tomography (CT) uses math to form an image by combining measurements from X-rays taken at multiple angles. CT is often used to image the brain. As depicted below, X-rays are directed through the head. These X-rays are detected and recorded on the other side of the head. The CT scanner rotates to take images in multiple locations around the head. Afterward, a computer combines all the images to show a single “slice” of the head. This process is called back projection.
Comparing CT Images with Standard X-rays

1) **Standard X-ray image** – human head

2) **CT slice images** – human head

3) **3D CT Image** – Slices from the previous set of images (No. 2) can be stacked together to create a three-dimensional model of a head.
How does back projection work?
Back projection is a method of combining data from multiple beams of X-rays to create a picture of the inside of the body. For instance, in the example below, X-rays are sent through the head from the back and right sides. We are looking at a layer of the head from the top. The intensity of X-rays exiting the front and left sides of the head are shown.

In this example, each beam passes through four points in the head. If we want to know the density of one of those points, we must combine data from the two beams that pass through that point. This is represented below by adding the values of the two beams at each point. In actual CT, back projection is more complex because it combines beams from many other angles.
Above, we used back projection to calculate the density of each of the points in the example head. These densities can be printed on a screen as an image of that layer of the head.

<table>
<thead>
<tr>
<th>X-ray data</th>
<th>4</th>
<th>2</th>
<th>1</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray data</td>
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<td>7</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>X-ray data</td>
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<td>2</td>
</tr>
<tr>
<td>X-ray data</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>X-ray data</td>
<td>8</td>
<td>12</td>
<td>10</td>
<td>9</td>
</tr>
</tbody>
</table>

To visualize the image, use markers to color in the numbers using the key provided below. This allows you to see an image just like a doctor sees an image when looking at a CT scan. In that case, the computer takes the number from the back projection and assigns a color or shade of gray to it to make the image.

<table>
<thead>
<tr>
<th>Number on Image</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3</td>
<td>Red</td>
</tr>
<tr>
<td>4-6</td>
<td>Orange</td>
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<tr>
<td>7-9</td>
<td>Yellow</td>
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<tr>
<td>10-12</td>
<td>Green</td>
</tr>
<tr>
<td>13-15</td>
<td>Blue</td>
</tr>
<tr>
<td>16-20</td>
<td>Purple</td>
</tr>
</tbody>
</table>

Tumors are often more dense than healthy tissue. Can you point out which point is most likely to be a tumor in the image above? It’s the section that blocks the most x-rays from both sides of the head showing that it is the most dense.
Now, you will do a back projection of your own based on the example we just did. Use playing cards to represent the data you measure. Use only the cards with numbers (no kings, queens, jacks) and use the ace to represent the number one. Place four cards horizontally and four cards vertically around a 4-by-4 grid. These cards represent the X-ray data from a CT scan. Each one is the measured X-ray intensity for a single X-ray beam.

For each square in the grid, add the number from the card at the top of the column to the number from the card in the row to the left. Write the answer in the square. This is how you do the back projection to create a CT image. Now, color in the boxes using the same color code provided before. You've just done a back projection to create a CT image from X-ray data!
Activity 4: Ultrasound and Submarines

When a submarine wants to find an object, it transmits a sound wave and then listens with a special device to see if the sound wave is reflected back. By calculating how long it takes for the wave to return, the people on the submarine can determine how far away the object is.

If Submarine A transmits a pulse moving at 1,450 meters per second and receives the echo 1 second later, then Submarine B is 725 meters away.

\[
\frac{1}{2} \left( 1450 \frac{m}{sec} \right) (30 \text{sec}) = 725m
\]

Now suppose that a submarine at the surface wanted to survey an underwater area that is 100 meters across. It wants to know how many submarines are below it that are 5 meters long or longer.

Draw lines down from the surface representing Sub A’s sonar:

1. Draw a line every 10 meters. How many subs did the line intersect?
2. Draw a line every 5 meters. How many subs did the line intersect?
3. Draw a line every 2.5 meters. How many subs did the line intersect?

How far apart must your survey lines be in order to detect all the submarines in the field?
Activity 5: Imaging with Sound

The images above show the device that transmits the ultrasound into the body and detects the returned ultrasound signal.
Medical ultrasound devices work much like the submarine surveying the field. But unlike our submarine, which moves along the surface of the water and scans every few meters, the ultrasound device uses a sensor that consists of many little “drums” in a line. Each drum can send and receive sound pulses. This allows the ultrasound device to survey a wide area at once. It is as if 50 submarines are lined up at the surface, imaging the depths of the ocean at the same time.

You are going to design your own echolocation system. It will function much like the submarine on top of the water. You will need to survey a field of objects (designed by your classmates) and determine where all the objects are.

**Part I: Build your location system.**
You must make a locator that moves along the long edge of your box and takes depth readings at specified positions. Remember, you must be able to tell precisely where your locator is taking readings and how deep the locator goes. Before you receive supplies, you must show your instructor the design you plan to use.

To build your location system you will receive:
- 1 box
- 1 pair of wooden chopsticks
- Ruler
- 1 sheet of graph paper
- Objects for bottom of sea floor
The following supplies will be available to you as you design your project, but you will have to share them with other groups:

- Markers
- Masking tape
- Pipe cleaners
- Wooden craft sticks
- Corrugated cardboard

**Part II: Build a terrain to stump your friends.**
Design a 3D terrain to test another team’s locator device. Tape the graph paper onto a piece of cardboard. Then, tape various objects on the paper to make your terrain. You will receive:

- 1 sheet of graph paper
- Corrugated cardboard
- Various small objects

**Part III: Test each other’s boxes.**
Exchange maps with another group. Put your map into another group’s locator box. Make sure the other group’s members are not looking when you do it. Challenge the other group to find all of the objects that make up your terrain.
Example “Terrain”

Your terrain may include anything that will fit inside the box. It can look like a landscape. It can include random objects. It could also be something specific. For example, it could be like the face of a baby inside a pregnant woman. The key is that your subjects be three-dimensional (ultrasound would not be able to detect a picture drawn on the paper).

Another group will have to figure out what your objects are by using its ultrasound device.