Communicating Science Concepts to Individuals with Visual Impairments using Short Learning Modules

A. S. Stender,[1] R. Newell,[1] E. Villarreal,[1] D. F. Swearer,[2] E. Bianco,[2] E. Ringe[1,2]*

[1]Department of Materials Science and NanoEngineering, Rice University, 6100 Main Street, Houston, TX 77005, United States

[2]Department of Chemistry, Rice University, 6100 Main Street, Houston, TX 77005, United States

Contents:

Brief Explanation of Module Scripts

On the following pages, the four modules discussed in the paper are presented. In each case, some background information about each topic is provided presenters should be made aware of this information prior to leading the module. The materials used to make the modules are also listed, together with brief descriptions on how to recreate each module.

Then, the basic script that was used to guide participants through each exercise is reported. Each script follows the same format: 1) statements and questions to be used by the module demonstrator are in quotation marks after the letter D (D: "text"), 2) Gaps in the script text are moments when the demonstrator can pause momentarily before moving on to the next statement, providing the participant an opportunity to speak or ask questions, 3) Instructions that should be followed at a specific point in the demonstration are underlined, 4) Notes meant for helping demonstrators are italicized and in parentheses (*italics*).

Out of courtesy, the demonstrator should always take a moment to greet each participant at the beginning and thank the participant at the end of the module. It is also good practice to speak to the participant by name during each module.

****

Making Modifications to the Modules

Educators, community service centers, and others wishing to utilize these modules are encouraged to make modifications to these scripts or to the experiments. The modules are reported here with several questions that were used to gather data on the effectiveness of the modules. These questions can be removed or modified according to the audience. Any questions or comments are welcome.

Module 1: Metric System

1.1 Overview and Objectives

This module has two purposes: to provide a tangible understanding of the metric system and to explain how small the nanoscale is. These two goals are accomplished by walking the participant through a set of six differently-sized objects that are mounted onto a wooden board. The board itself counts as a seventh object, because it is cut to 1 meter in length. The objects scale down in size by a factor of ten as the participant moves across the board from one object to the next. Since the board is a full meter in width, the first mounted object is one decimeter wide. The remaining objects scale down in size to one micrometer. The first two objects are rubber furniture bumpers, while the other four are selections of sandpaper with different sizes of grit. Grit sizes smaller than 1 micrometer are not available, but they would be difficult to distinguish from the 1 micrometer size. Some people will have a difficult time sensing the actual grit on the last two sheets, although they may notice that the two sheets have a different feel. Since a nanoscale object is not represented on the board itself, a brief discussion is held at the very end to explain that the nanoscale is even smaller, in fact 1000 times smaller, than one micrometer – the smallest size included in the demonstration.

1.2 Background and Notes to Demonstrator

The metric system is a convenient method for scientists to measure objects and to make mathematical calculations quickly, because it scales objects on orders of ten. Objects larger than one meter are difficult to present in a tangible demonstration, so the largest object here is the 1 meter board. Terms like centimeter and millimeter should be familiar to many people, but not everyone understands how large these objects are. As a result, the participants are presented with terms and sizes that should be familiar to them before moving to even smaller sizes and terms that fewer people will have considered before participating in this demonstration.

This module is intended for one participant at a time. If two are present, it is best to provide one board per participant. Feel free to touch them on the wrist and direct their hand to the correct place on the board. Also encourage them to go back and forth between the objects.

1.3 Materials and Preparation

The following materials are needed:

- 1 pine board, cut to 1 meter in length (costs $8 at hardware store)
- Magic Furniture Slider (4 inch / 100 mm, costs $10 for 4-pack)
- Surface Guard Vinyl Bumpers (3/8 inch / 10 mm, cost $2 for 16-pack)
- Sandpaper cut to 1 square decimeter. Use the following grit sizes, or equivalent: P20 (ISO scale), 150 (CAMI scale), 1000 (CAMI scale), 2000 (CAMI scale). (Prices vary from $5 - $20)

- Super 77 spray adhesive ($15-$20 per can)

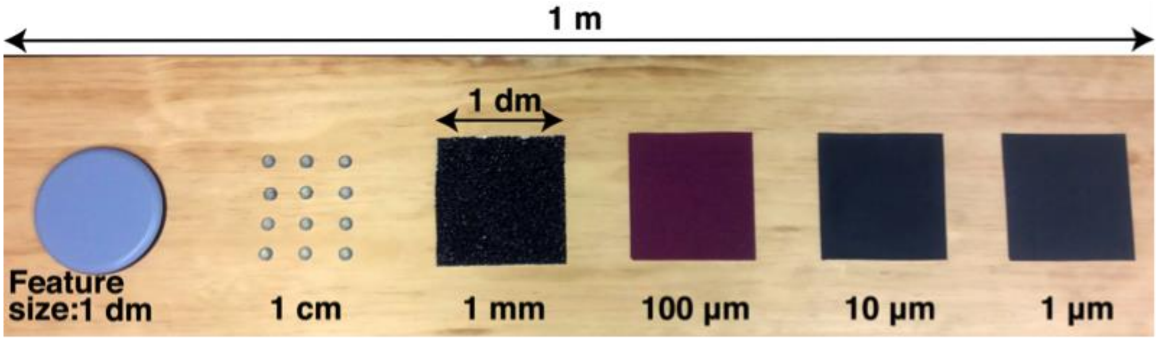

Figure 1.1: Demonstrator's board for the Metric System and Nano module.

To prepare the board:

- Space the objects evenly on the board.
- Use Gorilla brand construction adhesive to fix the magic furniture slider to the board.
- The vinyl bumpers come with adhesive on one side, remove the film and stick several to the board
- Adhere the sandpaper to the board using Super 77 adhesive (spray the back of the sandpaper, not directly onto the board).

1.4 Module Instructions

1.4.1 Setting Up

No special setting up is required for this module.

1.4.2 Script for Demonstrator

After greetings and introductions, the following script can be used by the demonstrator to guide the participant through the module:

Demonstrator begins, D: "Before we begin, I have a question for you. Have you heard of the metric system?"

(If the answer is yes) D: "How well do you understand it?"

(Many people may admit that they have heard of it, but they may not know much about it, or they may say that they are very familiar with it from school and work. The remaining questions can be slightly tailored based on these initial responses.)

D: "Put very simply, the metric system is a method for measuring the size of objects. Most Americans are more familiar with the English system, which measure distances in inches or feet or miles. The metric system is a good system for measuring the size of objects, particularly by scientists. The metric system scales up and down in steps of ten, which makes it a lot easier to do any math related to measurements."

Place the board in front of the participant, so that the largest object is on the participant's left.

D: "I placed a board in front of you. It has several objects on it, but first I want you to feel how wide the board is. It's a meter long. That's a standard size in the metric system, and it's an easy size to comprehend. It's also a good starting point for this exercise."

D: "Now I want you to find the object at the far left with your hand."

Help them as necessary to locate the object.

D: "That object is one decimeter across. If you put ten of those objects side-by-side, they would be as wide as the entire board."

(You can also tell them it's four inches wide if they are unfamiliar with the metric system, but after this object, try to emphasize metric units of length.)

Give the participant a moment to feel it and to make any remarks.

D: "When you are ready, let's move to the next object. This time, you will find a series of small bumps on the board. Each is 1 centimeter across. Just like before, if you put ten of them side by side, they would be as wide as the previous object that was a decimeter wide. Or, we can put 100 of them side-by-side, and they would be as wide as the entire board. That's what I meant earlier when I said that each step goes down by a factor of 10. Does that make sense to you?"

(Now is an ideal time to make certain the participant understands how the metric system scales by factors of 10. If he/she understands, then you can move a little more quickly through the remaining objects.)

D: "Let's go to the third object. This object is actually a piece of sandpaper, and it is cut to be one decimeter wide. Remember, our first object was one decimeter wide, too. When companies make sandpaper, they have to decide what size of sand or grit they want to put on the paper. The individual pieces of sand on this sandpaper are one millimeter across. That means, the piece of paper is one hundred times larger than the individual grains of sand."

(It is also fine to comment that it is difficult to find one millimeter sized objects (or smaller) that can be easily touched and mounted onto a board. That is why sandpaper is used for the remaining objects.)

D: "Now let's go to the next object. This is another piece of sandpaper one decimeter wide, but this time, the particles of sand are one tenth of a millimeter across."

(Give the participant a moment to touch the object.)

D: “When you are ready, we can go to the next piece of sandpaper. These particles of sand are one-hundredth the size of a millimeter.”

(Give the participant a moment to touch the object.)

D: “And when you are ready, we can move to the last piece of sandpaper. This is the smallest size of sandpaper that can be purchased. This size is defined as one micrometer, and it would take one thousand of these particles side-by-side to equal a millimeter.”

D: “Can you tell any difference between the last two surfaces?”

(If participant answers yes) D: “What is different about them?

D: “At this scale, some people can still feel a difference, while others cannot. Whether a person is looking at this sandpaper or feeling it with their hands, the particles are now so small that it is difficult to distinguish between sizes. Companies don’t make sandpaper with grain sizes much smaller than this, but if they did, people would need to use special equipment to measure the grain sizes, because they are too small to distinguish very well by touch or sight. In scientific research labs, people frequently work with materials that are a few nanometers across. Usually microscopes and other tools are used to study materials that small. When you hear about nanotechnology or nanomaterials, people are talking about objects that are smaller than the grains on that last piece of sandpaper you felt. In fact, if we wanted sandpaper with one nanometer sized grains, it would take three more of these steps to get down to a single nanometer.”

(Now is a good opportunity to discuss “nano” in greater detail, but it depends on time and the interest level/understanding of the participant. It is worth keeping in mind that in the broadest terms, the term nanomaterials encompass objects that range from one nanometer up to one micrometer. However, many scientists define nano as the range of 1 – 100 nanometers.)

D: “Now that we have finished, do you have a better understanding of the metric system?”

<u>Take a few moments to answer any questions and then thank the participant for stopping by.</u>

Module 2: Materials Transparency

2.1 Overview and Objectives

The objective of this module is to explain simple light-matter interactions. To accomplish this purpose, an apparatus monitors differences in the light intensity of a lamp and transduce this intensity to a sound volume. The light intensity is then manipulated by placing various materials between the lamp and the light intensity sensor.

2.2 Background and Notes to Demonstrator

Light can interact with materials in a variety of ways depending on the composition of the material. The most common light interactions are absorption and scattering, which are at the basis of concepts such as transmittance, translucence, and opacity. Transparency occurs when a material allows most or all light to pass through, without being absorbed or scattered. Translucency occurs when a material allows some of the light to pass through, but scatters a significant fraction of it. Thus, translucent materials wouldn’t make for good lenses or windows, because they disrupt the intensity and clarity of images that are passed through them. Finally, opaque materials reflect, scatter, and absorb all of the incoming light, preventing light from passing through.

This module can be presented to two or more people at a time, in which case the hands-on demo should be repeated for each participant. The presenter should help the participants position their objects to the setup. It is very important to let the participant know where the lamp is facing, so they have a better understanding of what occurs during the module.

2.3 Materials and Preparation

The three main components in the setup are speakers, a lamp, and a platform with the light sensor (Figure 2.1). The light sensor is attached to a foldable platform, which allows the user to easily configure its position. The lamp has a magnet at the bottom in order to attach it to the metal frame in the bottom of the metal foldable platform.

The objects used in this module are glass slides, paper stacks, cardboard stacks, and cellphone screens (Figure 2). The edges of the glass slides are smoothed to avoid sharp edges. The paper stacks are prepared by stapling 3 sheets of paper, and the cardboard stacks are made out of two thin pieces of cardboard stapled together. The cellphone screens are iphone-5 replacement screens/digitizers.

Figure 2.1: Depiction of the setup containing the photo resistor, lamp and speakers. The lamp faces the light sensor, which correlates light intensity with sound volume.

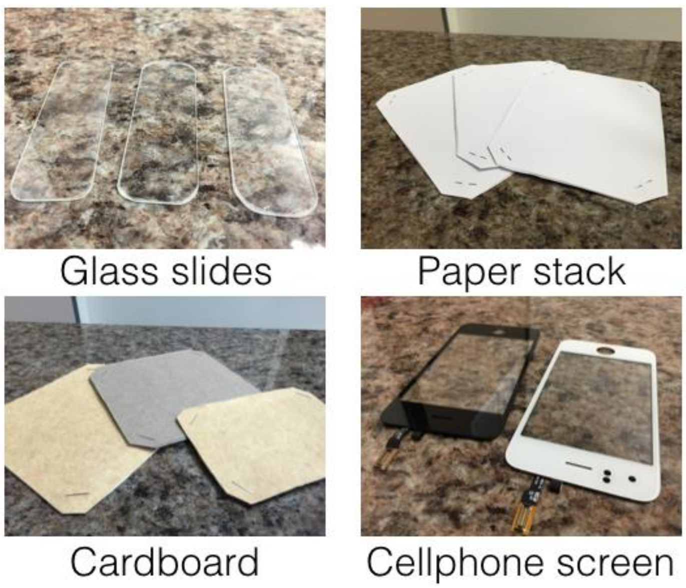

Figure 2.2: Depiction of the module's samples.

The following materials are needed:

- Snap Circuits Junior (for the circuitry of the module) - $29.99
- Cyber Acoustics 2.0 Dynamic Speakers – $11.86
- LED 110V light magnetic base gooseneck lamp - $14.90
- Sunydeal articulating TV wall mount - $14.99
- iPhone 5 touch screen digitizer – $12.20
- Hammond 1591 ESB KABS project box - $7.81

2.4 Module Instructions

2.4.1 Setting Up

Set up the module as follows:

- Turn the lamp on
- Turn on the light sensor by using the slide switch. By turning the system on and off, different sounds will be played. Choose an appropriate sound.
- Turn on the speakers and get familiar with the speakers volume knob
- Turn the volume down

2.4.2 Script for Demonstrator

After greetings and introductions, the following script can be used by the demonstrator to guide the participant through the module:

Demonstrator begins, D: “Are you familiar with the concept of transparency?”

(If the answer is yes) D: “Can you tell me what it is?”

D: “Transparent materials are very important in the development of new, sustainable technologies from solar cells to cellphone screens. These materials have specials properties that allow light to pass through them.”

D: “Now, we are going to go through a module that explains and demonstrates how materials either absorb or transmit light. Objects vary in how they transmit light. Transparent objects allow light to travel through them. I am now going to hand you a glass slide, an example of a transparent material.”

<u>Hand the coverslip(s) to the participants</u>

D: “When light encounters transparent materials, almost all of the light passes straight through them. Glass, for example, is transparent to all visible light.”

D: “Translucent objects allow some light to travel through them. Materials like frosted glass and some plastics are called translucent. I am going to hand you a stack of paper as an example of a translucent material.

<u>Hand them a stack of paper.</u>

D: “When light strikes translucent materials, only some of the light passes through. The light does not pass straight through the materials. It changes direction many times and is scattered as it passes through, as opposed to transparent materials. Therefore, sighted people cannot see clearly through translucent materials, but if you try to look through a translucent material at an object, the object will appear fuzzy and unclear.

D: "Opaque objects block light from traveling through them. Most of the light is either reflected by the object or absorbed and converted to heat. I'm going to hand you a piece of cardboard, as an example of an opaque object."

<u>Hand them the cardboard.</u>

D: "Materials like wood, stone, and metals are opaque to visible light. In order to conceptualize these transparent, translucent, and opaque concepts, I'm going to use a sound setup. In front of you, there is a setup composed of a lamp and a light sensor. You are going to hear sound coming out of speakers."

<u>Slowly turn the volume up, so they can hear the sound.</u>

D: "Can you put your hand forward, so I can explain you the set up?"

<u>Direct their hand(s) to the lamp.</u>

D: "This is a lamp, and it's going to be our source of light. It is facing to your left."

<u>Help them placing his/her hand in front of the light sensor.</u>

D: "This is the light sensor, and it correlates the intensity of the light with the intensity of the sound. This is how it sounds when all of the light is passing through."

<u>Allow them to hear what it sounds like when all of the light can reach the light sensor.</u>

D: "And notice how the volume goes down when you cover the light sensor."

<u>Help them cover the light sensor.</u>

D: "Now can you place the glass slide in front of the light sensor?"

<u>Help them only as necessary.</u>

D: "Notice how the intensity of the sound is not affected when you placed this material in front of the light sensor. That is because glass allows all of the light to pass through. So, no light from the lamp is absorbed by the glass.

D: "Now, can you place the stack of paper in front of the light sensor?"

D: "Notice how the intensity of the sound decreased. That is because the paper is both absorbing and transmitting the light from the lamp."

D: “Finally, can you place the cardboard in front of the light sensor?”

D: “Notice how the sound is very low or can’t be heard. That is because cardboard absorbed or reflected all of the light from the lamp.”

D: “Transparent materials are very important to modern technologies. I’m going to hand you a cellphone screen, but first, can you hand me back the glass slide, paper stack and the cardboard?”

Collect the materials and hand them the cellphone screen.

D: “This screen is a replacement from an iPhone, which has a conductive layer that detects when and where you touch the screen. Engineers and scientists developed a method to fabricate a conductive material that is also transparent, enabling the modern cellphone configuration. Now, place the cellphone screen in front of the light sensor, and notice how this material does not affect the intensity of the sound. This is because the conductive screen let all of the light go through it.”

Once you finish demonstrating this section, ask them to hand you back the cellphone screen.

D: “To summarize what we learned, materials can be characterized into three groups that are dependent on how much light they allow through: transparent, translucent, and opaque. Transparent materials transmit all of the light, like the coverslip you had. Translucent materials let some light pass, absorbing and reflecting some of the light and transmitting the other part, like the paper stack you had. And finally, opaque materials do not transmit any light, like the cardboard. This is because opaque materials absorbs and reflects back all of the light.

D: “Thank you for your attention, and I’ll be happy to take any questions.”

Module 3: Strength of Materials

3.1 Overview and Objectives

This module is designed to explain the properties of strength in materials. The module explains the concepts of deformation, fracture, and fatigue. The types of deformation are demonstrated with hands-on experiments. This module is best taught in a one-on-one setting.

3.2 Background and Notes to Demonstrator

This module covers five topics: 1) an introduction to Materials Science, 2) elastic deformation, 3) plastic deformation, 4) flaw mechanics, and 5) fatigue.

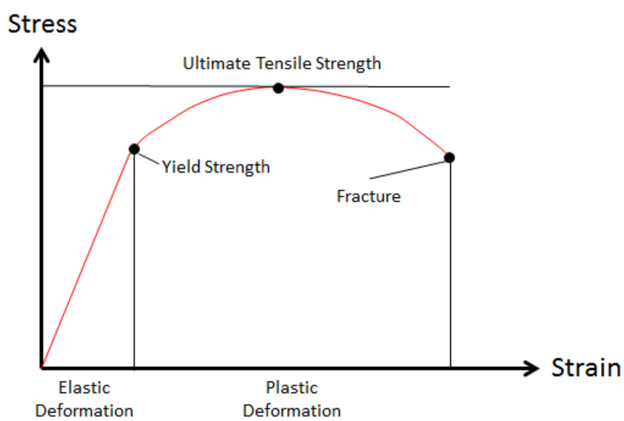

Figure 3.1: Stress/strain curve. As more force (stress) is applied, more deformation (strain) results. Materials deform elastically then plastically before breaking. Adapted from Callister, W. D.; Rethwisch, D. G. *Fundamentals of Materials Science and Engineering: An Integrated Approach*; Wiley, 2012.

Stress is the applied force divided by the area where the force is applied. Strain is the relative change in length of an object as it is deformed. The slope of the elastic line in Figure 3.1 is called Young's modulus or the modulus of elasticity; lower values mean a more elastic material. If a material greatly deforms (high strain) with little force (low stress), then it will be very elastic.

All materials undergo a curve similar to this to varying degrees, but the shape of the graph is different depending on the properties of the material. Flaws exist in most materials in varying amounts. Flaws and defects make the material drastically weaker than their theoretical strength. The reason this happens is that these defects concentrate the forces applied to the material to a small area, while a flawless material would distribute it equally. If the force is concentrated in a small area, the stress in that area becomes very high and causes the material in that area to fail, expanding the flaw and further weakening the material.

Fatigue only occurs during plastic deformation, and depends on the temperature of the material and how many times it is plastically deformed. This is why engine parts and jet turbines are particularly susceptible to fatigue. They operate at high temperatures and often have rapidly moving parts. Even if they only have a slight plastic deformation, fatigue can quickly destroy them.

3.3 Materials and Preparation

The following materials are needed:

- Modeling Clay
- Plastic Zipper Bag (Ziploc or another brand)
- Metal Paperclip
- Rubber Band
- Paper

All of these are relatively common to find and can be purchased online or in stores. The materials are relatively inexpensive, but some may only be sold in bulk, which can drive the total cost to $30-50.

The zipper bag should be cut first to separate the zippers (the top) from the sides. The sides should be further cut into vertical and horizontal strips, as shown in Figure 3.2. If necessary, the grain direction of the plastic can be determined by holding the plastic up to a light and looking for lines. To make it easier to remember the grain orientation, mark the direction of the grain with a permanent marker.

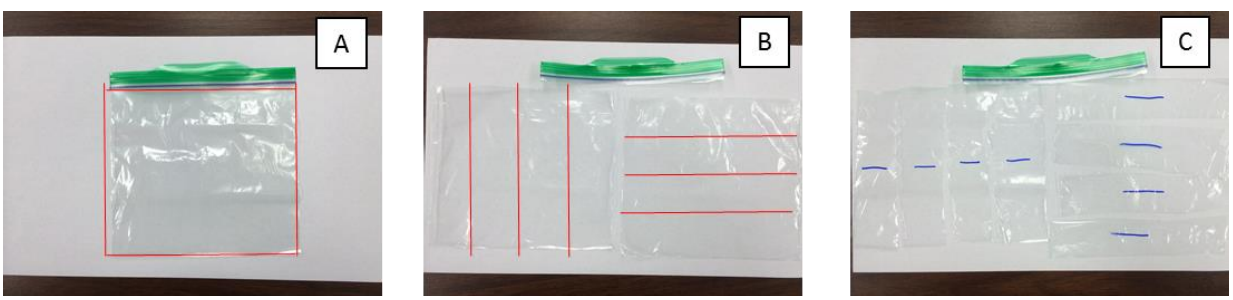

Figure 3.2: The process to create the plastic bag pieces used in the module. Cut along the red lines. C shows the finished product with blue markings highlighting the polymer chain direction

3.4 Module Instructions

3.4.1 Setting Up

- Assemble one of each item
- Roll the modeling clay into a rod

3.4.2 Script for Demonstrator

After greetings and introductions, the following script can be used by the demonstrator to guide the participant through the module:

Demonstrator begins, D: "On a scale of 1 to 5, with 1 being no knowledge and 5 being college level, how much do you feel you know about the strength of materials?"

D: "Have you heard the term 'Materials Science' before today?"

D: "Materials science is the study of materials and their properties. Materials Scientists create and study materials like stainless steel and plastics. These materials all have different properties, and the most important property is strength. Whether building a toy or a bridge, the materials used must be strong enough. However, the concept of strength is more complicated than just how much force it takes to break something. One important part of strength is deformation. Before anything breaks, a material bends and changes shape. How they deform and when they break is important in understanding how strong materials are, and is a vital property of machinery such as jet engines. In this module, we will talk about the deformation of materials, do a small experiment, then briefly cover flaw mechanics and fatigue."

D: **"**There are two types of deformation; elastic is the first type of deformation that occurs."

Hand them a rubber band, and encourage them to stretch it as they wish.

D: "A rubber band is a good example of elastic deformation. When it is pulled, it will deform and stretch, but it will return to its original shape. Please note that ALL materials can undergo elastic deformation, but certain materials are far more elastic than others. For example a rubber band is far more elastic than a dinner plate."

(At the atomic level, the lattice stretches, but the overall pattern remains unchanged. When the tensile force is removed, the lattice returns to normal.)

Hand them a metal paper clip.

D: "That paper clip is made of metal. This is important, because the concept of plastic deformation applies to all materials, despite its name."

D: "Find the outside end, that is, the pointy part, and lightly pull on it."

D: "This is another example of elastic deformation, as the paperclip will snap back. However, if you pull on it hard and try to straighten it out, it will permanently change shape. Go ahead and straighten it out if you can. This is known as plastic deformation. Once a certain amount of force has been applied, the material will stop deforming elastically and begin to deform plastically.

D: "Different materials can undergo different amounts of plastic deformation before breaking. For example, the rubber band can elastically deform a lot by pulling it short distances, but it will break without much plastic deformation if you pull on it hard and stretch it to the extreme."

D: "The paper clip undergoes a lot of both types of deformation."

D: "A ceramic dinner plate will barely deform, but it will shatter quickly. Any deformation by a ceramic plate would be difficult to notice."

D: "Do you have any questions about deformation?"

D: "Now we are going to try a little experiment. When Materials Scientists want to analyze the strength and deformation of a material in the lab, they perform a tensile test. This test uses a machine to slowly pull samples apart until they fail. The machine measures at what strength the material breaks and how the material deforms as pressure is applied.

D: "In this experiment, you will be performing a tensile test by hand. I will give you several materials, and you will test their strength and deformation."

(Do not tell them what the materials are until later in the script.)

D: "Hold out your hands with your palms facing upwards. When you feel something in your hands, grab the tips and begin pulling gently. Gradually increase the force until the material fails. Increase the force slowly and pay attention to how far your arms move apart, as well as how hard you are pulling. Do not twist the material, because it makes it much harder to break."

<u>First, give them the modeling clay. Make sure it is shaped as a rod. Make sure they start out with a light force and gradually increase the pressure.</u>

<u>Second, give them the plastic (parallel). The grain should run parallel to the long end of the strip.</u>

<u>Third, hand them the next plastic (perpendicular).</u>

(The order in which the plastic is tested is not very important. Just make sure they don't get the same type of strip twice.)

<u>Fourth, hand them the plastic zipper.</u>

(The zipper and some of the plastic pieces may be difficult to pull apart. If it looks like the zipper is not fracturing, tell them it is okay to stop without breaking it. Often the plastic is slippery and they cannot get a good grip.)

<u>After they finish testing all of the materials, ask these follow up questions.</u>

D: “Which one deformed the most before failing?”

D: “If the materials underwent elastic deformation, it would feel as if they were exerting a force against your hands. With that in mind, could you feel elastic deformation from any materials? If so, what materials felt the most elastic?”

(This answer may vary depending on how they pulled at the materials.)

D: “A device called an instron is used to determine when elastic deformation ends by comparing the amount of force needed to pull a material as far as it will deform.”

D: “Which material was the strongest? That is, which took the most effort to fracture?”

D: “Can you guess where the different materials came from?”

Reveal what the materials were and tell them that both plastics are the same material, just pulled in different directions.

D: “This is an important concept, because materials can have different strengths based on their grain orientation. Other examples of this would be fabric, duct tape, and wood. For fabric or duct tape, they are normally very durable, but can be easily ripped if torn in a certain direction.”

D: “Do you have any questions about the tensile test experiment?”

D: “There is more to strength than deformation. We will briefly cover two more strength concepts, flaw mechanics and fatigue. Flaws are defects, such as cracks, in the structure that weaken the material as a whole.”

Give them a sheet of paper. Tell them to pull on the paper from the middle in two directions (Figure 3.3.A).

D: “Paper is actually surprisingly strong on its own.”

Have them rip the paper (Figure 3.3B) and try to pull it apart from the edges of the tear.

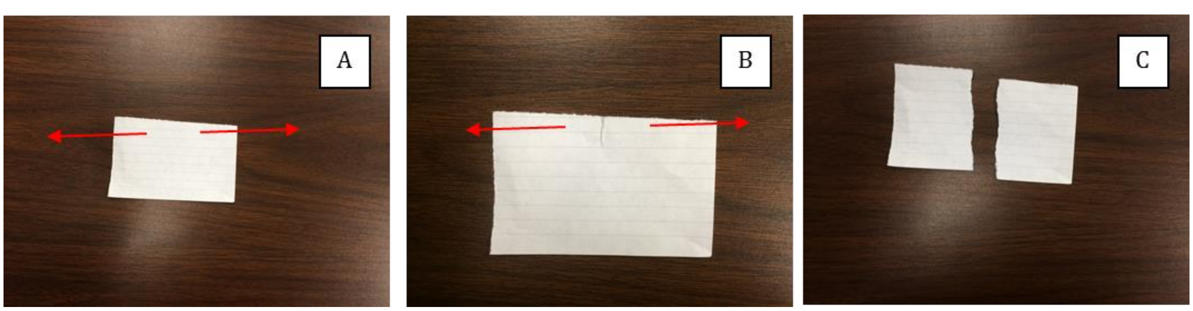

Figure 3.3: Tearing paper to demonstrate fracture mechanics. Red arrows indicate where to apply force.

D: “Notice how the tear grows as force is applied and cuts through the paper. This shows how flaws in the material can drastically weaken it. This cracking can occur at the micro level and severely weaken materials. Many industrial accidents and other disasters are caused by these flaws. An interesting example of flaw mechanics is glass. Glass is theoretically very strong, but the process of creating it introduces thousands of micro fractures throughout the glass. Then, when the glass is hit, the force will move through these fractures and shatter the glass.”

D: “Do you have any questions on fracture?”

D: “Fatigue is another important concept, and the last we will cover. The more an object is plastically deformed, the weaker it gets.”

Give them the paperclip from earlier. Remind them how they plastically deformed it.

D: “You applied a certain amount of force, but it did not break. However, if you were to apply the same force 20-30 times, the material would eventually break. This process is known as fatigue and it occurs because every time a material plastically deforms, it weakens. Fatigue is another huge problem in engineering, and is the reason most machinery or high stress materials need to be inspected regularly.

(It is not necessary for them to bend the paper clip in an effort to break it, although let them try if interested)

D: “Do you have any questions about fatigue?”

D: “Hopefully, this served as a good introduction to strength and deformation. These concepts apply universally to all solid materials. Also, these concepts are very important in the field of materials science, and they are used in engineering applications across the globe. Even outside the field of engineering, strength is an important property, and these properties of strength can be observed in daily life.

D: “Do you have any remaining questions about the demonstrations?”

D: “To wrap up, I have a few questions for you. Were the concepts presented totally new or have you had experience with these concepts before?”

D: “Which concept, deformation, flaws, or fatigue, was the easiest to understand?”

D: “Which was the hardest to understand?”

Module 4: Hearing the Electromagnetic Spectrum

4.1 Overview and Objectives

The objective of this module is to communicate the following three points: 1) the electromagnetic (EM) spectrum consists of waves and the different frequencies (or wavelengths) of these waves dictate what type of "signal" or "radiation" is present, 2) visible light is a very small fraction of the EM spectrum, and 3) both acoustic and EM signals propagate as waves.

It is important to note that acoustic waves can be applied *as a model* for demonstrating different EM frequencies; but the sounds that the participants hear are *not a true representation of, and not the same energy as, the* assigned EM frequency.

In this module, a function generator, oscilloscope, and speakers/headphones are used to visually and audibly demonstrate the electromagnetic signals hidden from view. Objective 1 can be accomplished by working with multiple frequencies as provided in Table 4.1. Objective 2 can be accomplished by explicitly demonstrating the yellow highlighted section on Table 4.1. Objective 3 must be verbally communicated during the initial dialogue with participants. We have found in our testing that the relationship between the defined acoustic and EM frequencies must be made explicitly clear. That is to say, the sounds are modeled *on an arbitrary scale* and 8.8 kHz is not the "sound" of red light. This arbitrary scale model was useful in adapting the module to accommodate each participant's audible frequency range. This module can be presented to two or more people at a time, in which case the hands-on demo should be repeated for each participant. An oscilloscope is included for those who are able to see; however, for the visually impaired a physical model of the waves, i.e. providing a haptic alternative, may be necessary. An additional limitation of this demonstration occurs for those with severe intellectual disabilities. In our demonstrations, we observed that there can be confusion between acoustic and EM signals, which can be remedied by careful explanation and frequent questioning to reinforce the concepts under discussion. Additionally, participants benefited when an understanding of the basic properties of waves (frequency, wavelength, etc.) could be achieved.

4.2 Background and Notes to Demonstrator

Our daily lives are saturated by noise from the electromagnetic (EM) spectrum: from visible colors that decorate daily objects to the invisible signals of our WIFI and cell phones. The wavelengths covered by the EM spectrum spans an incredible range of ~21 orders of magnitude! For the visually impaired, a small (~1 order of magnitude) portion of the EM spectrum is hidden from perception. For everyone else, we are blind to the other portions of the EM surrounding us.

Fortunately, the EM waves that are invisible to us all can be contrasted with sound waves. Acoustic sound waves are pressure waves that interact with our ears drums and cause us to register different frequencies of sound. Even though these two types of waves, electromagnetic and acoustic, act on different organs (eyes vs. ears, respectively), the nature of these waves is similar.

An order of magnitude can be explained in terms of the 'scales' in the scale demo (module #1 above). A centimeter is an order of magnitude smaller than a decimeter, for example. Another way to describe the immensity of the EM spectrum is to say that if it were divided into equal parts it would be comprised of 10^{16} parts!

Frequency is defined by the number of oscillations within a given period. If a ball is dropped from the top of a building (let's assume this is in space), and it bounces 120 times in one minute, the ball has a frequency of 2 Hz. A Hertz (Hz) is a common unit with a scale of 1/seconds, and is also known as "Repetition Rate" or rep rate.

It is especially important for demonstrators of this module to note the following:

- The scale starts at 10,000 Hz. However throughout our testing, some participants reported that this high frequency is outside of their hearing range. Rescaling may be necessary depending on the audience.
- In between the "frequencies" demonstrated, it is helpful to turn off power to the speaker (and also while making frequency changes). This acts as a switch and allows for very distinct changes in the tones. At the end of the module, scrolling back through the frequencies from low-to-high without turning off the power gives an idea of how far we've gone.
- Do not feel obligated to go through each step frequency step shown here. For the sake of time, it is advisable to show only 10-12 examples out of the 20 on the list; however, please include the highlighted row in the demo to show where visible light appears on this spectrum.

4.3 Materials and Preparation

The following materials are needed:

- Instek GDS-1052-U 50MHz Digital Oscilloscope 2CH - $316.80
- Instek AFG-2005 Signal Generator, Arb/Function, 5MHz – $295.00
- Logitech Speaker System Z313 – $34.99
- Belkin RockStar 5-Way 3.5-mm Headphone Splitter (White) – $14.92
- Stanton DJ-PRO 300 Single Sided DJ Headphone – $39.99

The electronic set-up contains 3 parts as shown in Figure 4.1. Three power outlets are necessary for this demonstration.

There should be one cable leading from the sync output on the function generator to the speakers. Both alligator clips should be placed on the plug coming from the speakers; adjust as necessary.

The other cable is connected to the function generator and oscilloscope. Please note that this is not required for sound generation, but to visualize the sinusoidal wave on the oscilloscope. This connection should be made from main output to CH1 on the oscilloscope.

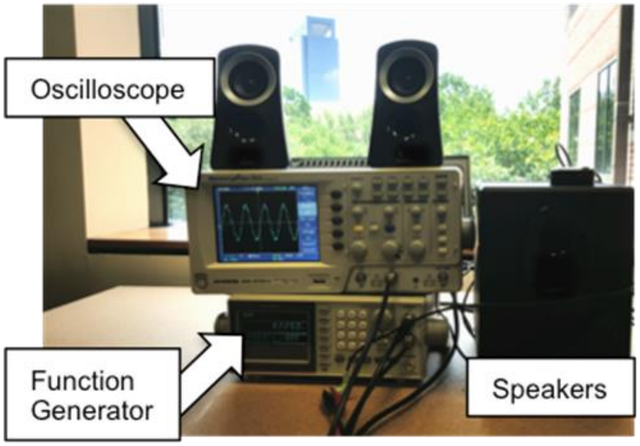

Figure 4.3: Module Set-up with speakers on top, oscilloscope in middle, function generator on bottom.

4.4 Module Instructions

4.4.1 Setting Up

- Turn on the Oscilloscope: Use the power button in the front bottom LEFT corner.
- Turn on the function generator: Use the power button on the front bottom RIGHT corner.
- Turn on the speakers: A small button on the control panel will turn on the speakers and a green light will illuminate. Volume can also be controlled from this location.
- The frequency of the sound can be controlled by first pressing the FREQ button on the front panel of the function generator (Figure 4.2).

The large circular knob to the right of the numerical pad is used to adjust the frequency. Turning this knob to the right will increase the frequency. Turning to the left will decrease it. The frequency step size can be tuned by using the two arrow keys underneath the large knob.

NOTE: The blinking digit on the digital display is the digit that changes upon rotation of the knob.

The demonstration can begin once the setup is complete. Table 4.1 gives suggested acoustic frequencies and the corresponding electromagnetic counterparts, as well as two examples of objects with comparable sizes to the wavelength of the EM spectrum. Change the FREQ button as described above to work this module.

Figure 4.4: Use the FREQ button (second from the top, on the right next to the display panel) to adjust frequency.

4.4.2 Script for Demonstrator

After greetings and introductions, the following script can be used by the demonstrator to guide the participant through the module:

Demonstrator begins, D: “Have you heard the term radiation?”

D: “What can you tell me about your understanding of radiation?”

D: “Light is a form of radiation. Radiation is just travelling energy, and light is only one type of radiation. For example, heat is also radiation. Other examples of radiation are X-rays, UV light from the sun, and cell phone signals. In fact, they are a part of the same “spectrum”, because they are all forms of energy.”

D: “Have you heard the term ‘spectrum’ before?”

D: “A spectrum is just a way to measure a range. In the first module you did, you looked at a spectrum of sizes. Here, we are listening to a spectrum of energy. Human eyes can only see a very small part of the electromagnetic spectrum known as visible light, but there are also higher and lower energy waves that we cannot see. We have developed a way to represent light waves as something you can hear!”

<u>At this point, have the participant put on headphones, if available. The remainder of the script is adlibbed. Adjust the apparatus to an “acoustic frequency”, name the radiation, read the size, and give an example or two from the list in order to inform the listener to the size of the wavelength. Move to the next wavelength and continue through the process until at least 10 different examples are tried. After that, do more as time permits, and refer to the demonstrator notes in</u>

section 4.2. This module has no concluding questions, but do leave time at the end for questions and a short discussion about the participant's experience.

Table 4.1: Suggested acoustic frequencies with corresponding electromagnetic counterparts. The objects listed are meant as examples of objects of the same size as the EM wavelength listed. The row representing the Visible range of light is highlighted as a reminder to include this example for every participant.

Acoustic FREQ (Hz)	Wavelength	Ex. 1	Ex 2.	EM radiation Name
10,000	*10pm*		*1/3 the covalent radius of a Hydrogen atom*	*Gamma Rays*
9500	*100pm*	*Size of a Sulfur Atom*	*Bond distance between C-C bonds, or thickness of a graphene sheet*	
9000	*1nm*	*Diameter of DNA helix*	*Small Proteins (5-10nm)*	*X-RAYS*
8500	*10nm*	*thickness of a cell membrane*	*Size of the smallest computer processor (16nm)*	
9000 [VISIBLE ~8800-8600Hz]	*100nm*	*Diameters of HIV virus (120nm)*	*Standard Depth of pits on compact discs (CDs) (125nm)*	*Ultraviolet (100-400nm) VISIBLE LIGHT (400-700nm)*
8500	*1um*	*Small Bacteria (1-10um)*	*Typical size of a human spermatozoon's head (5um)*	*Infrared*
8000	*10um*	*Intel 4004, worlds first microprocessor (10um)*	*Human red blood cell (10um)*	
7500	*100um*	*Width of Human hair (100um)*	*Average size dust particle (~100um)*	

7000	*1mm*	*Diameter of a pinhead*	*Length of the average flea (1.5mm)*	
6500	*10mm*	*Width of a fingernail*	*Size of a large mosquito (1.5cm)*	*Microwaves*
6000	*100mm*	*Size of the worlds largest beetle species (150mm)*	*Average length of a human foot (290mm)*	
5500	*1m*	*Wavelength of FM radio broadcast (2.77-3.44m)*	*Height of a basketball net (3.05m)*	*FM Radio*
5000	*10m*	*Average AM radio broadcast (31m)*	*Length of a London Buss (8.5m)*	*AM Radio*
4500	*100m*	*Length of a football field (91m)*	*Height of the Pyramid at Giza (138.8m)*	*MF Radio*
4000	*1km*	*Worlds tallest waterfall [Salto Angel, Venezuela] (973m)*	*Worlds Tallest Building [Burj Khalifa, Dubai] (829m)*	*Span of Golden Gate Bridge (1.28km)*
3500	*10km*	*Diameter of Dietos, Mar's small moon (13km)*	*Length of a Marathon (42.195km)*	
3000	*100km*	*The Karman Line; the distance to outer space*	*Distance from Washington, DC to Chicago (956km)*	
2500	*1000km*	*Distance from San Diego to El Paso (1010km)*	*Worlds Longest Bicycle Race (1200km)*	
2000	*10,000km*	*Diameter of Earth (12742km)*		
1500	*100,000km*	*Diameter of Saturn (120,000km)*	*The distance light travels in one second in vacuum (300,000km)*	*Longest EM waves known*

5. Additional Comments made by Study Participants

5.1. Strength of Materials Comments/Questions

- A participant that previously worked for Continental Airlines asked about fractures and fatigue in airline maintenance.
- A participant was very interested in the art of glass blowing, and asked to elaborate on how the strength of glass worked in glass blowing
- A participant asked about a time when his/her car broke down, and what might have caused it
- A participant asked about strengthened glass and flexible glass used for security purposes after the explanation on fracture

5.2. Full Answers for Hearing the EM Spectrum Questions

5.2.1 "Other than visible light, what forms of radiation are present around us? "

(one line per participant, invalid answers italicized):

- Radio waves, cell phone signal
- Microwaves, X-rays
- Heat, X-rays, microwave
- X-rays, gamma rays, UV, IR
- X-rays, microwaves, IR
- Cell phone signal, microwave
- X-ray, microwave, IR
- Heat, radio signals
- *Helicopter/airplane sounds*
- Microwaves, the sun, *skin radiation*
- X-rays, microwaves, radio frequency
- Radio waves
- Radio waves, microwaves, cell phone signal, *anything that makes noise*
- UV, IR, microwave, X-ray, gamma rays, radio waves
- *Could not name*
- IR, microwaves, radio, cell phone signals
- Radio waves, microwaves, X-rays

Table 5.1: Summary of answers to "Other than visible light, what forms of radiation are present around us?"	
Answer	**Frequency**
Microwaves	11
Xrays	8
Infrared (heat)	7
Cell phone	4
Radio	4
Gamma rays	2
UV	2
Helicopter/Airplane sounds	1
The Sun	1
Skin Radiation	1
"Anything that makes noise"	1
Couldn't name	1

5.2.2 "Do you feel you learned something about the world around you?"

- Yes, radio waves have frequency
- No
- Yes, radiation has a much broader range. Blue is higher frequency than red
- Yes, how sound can correspond to different colors
- Yes, that color has an audible frequency, that microwaves and radiowaves have low energy. It would be great for blind people to have a way to hear color
- Yes, that radiowaves are such low energy [He figured microwaves would be lower than radio, but they are not]
- Yes, did not know colors could be represented as sound
- Yes, better understanding of radiation and higher pitch sounds are higher energy
- Yes, different sounds mean different waves like microwave and radiowave
- Yes, never knew that there were radio waves. That frequency changes with pitch. "The wave gets smaller as the sound gets higher" (Visualized from the oscilloscope)
- Yes, all the different types of radiation – didn't realize how expansive the spectrum is (i.e., Xray & microwaves are radiation) – there terms are so common that the participant didn't "connect the dots" & that color has a frequency
- Yes, that the color blue color be represented by sound
- Yes, that different types of radiation have energy, that sounds/colors "count as energy"
- Yes, that FM radio waves are a form of radiation
- No
- Neat to hear the pure sound of a radio wave
- Yes, didn't know you could hear frequencies that represent colors.

5.3. Answers to Post-Activity Questions

5.3.1 "What parts of there lessons did you most enjoy"

- The explanations
- The EM spectrum module
- Learning about fatigue
- The clear descriptions given by the demonstrators
- Breaking materials
- The sound [EM spectrum module]
- The frequency waves [EM spectrum module]
- All-it was very interesting
- The light [transmission module]
- All
- The radio wave [EM spectrum module]
- Light [transmission module]
- Everything
- The radiation [EM spectrum module]
- Learning that radiation can be represented by sound [EM spectrum module]

5.3.2 "What can be improved upon?"

- The sounds are not different enough [in the EM module]
- The volume was too high [in the EM module]
- Nothing, it was all neat!
- More tactile experiments
- More touch-based modules

5.3.3 "Are there any other scientific topics you would like to learn more about in the future?"

- Biology/dissections
- Physics
- Medicine or technologies for improving the life of visually impaired individuals
- Hearing stuff, learning about how we hear
- Animals, wildlife
- How the eye work
- Everything
- Doing more science
- Astronomy, planets, volcanoes