Safe Alternatives For Hands On Learning Of X-Ray Imaging Principles

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Abstract

Hands-on learning of x-ray imaging principles using actual x-ray equipment is unrealistic due to high equipment costs, limited availability of such devices, and, most of all, safety concerns. Computer simulators can substitute for hands-on learning but are not necessarily as effective, especially for kinesthetic learners, and typically limit the amount of collaborative work possible. The objective of this work is to teach principles of x-ray imaging using a creative, safe and inexpensive alternative to "real" hands-on-learning. Visible light is used in specially designed exercises to teach the principles of attenuation, magnification, penumbra, and detector resolution. An exercise to teach the principle of attenuation is described in detail in this paper.

Introduction

Hands-on, collaborative learning is a useful style for many learners and has the potential to increase the participation of women and minorities in science and engineering. Research has shown that young women learn science well in classrooms that use hands-on investigations[1, 2] as described in this paper. Girls learn well when coursework is collaborative[1, 3, 4] and utilizes girls' verbal skills[4]. Girls learn science better when the curriculum clearly links mathematics, science, and technology to the real world[4, 5, 6], and integrates these topics as well[7]. X-ray imaging is a topic that definitely integrates mathematics, science, and technology and has obvious impact in the real world. Most children have some experience with x-ray imaging, either through dental or skeletal x-rays taken of themselves or of others they know.

Young African American children have been shown to have a relational style of learning[8] that closely aligns with the sensing-perceiving temperament personality description[9] of students who need active hands-on experiences in the classroom and need to see the relationship between theory and reality[10]. Hispanic students have been shown to learn science better when the students are expected to actively participate and when the assessments reflect the fact that instruction has different results for different learners[11]. Because Hispanic cultures value mutual assistance, collaborative work in the classroom is effective[11]. Interactivity with concrete manipulative materials assists students in mastering concepts and problem-solving skills[12].

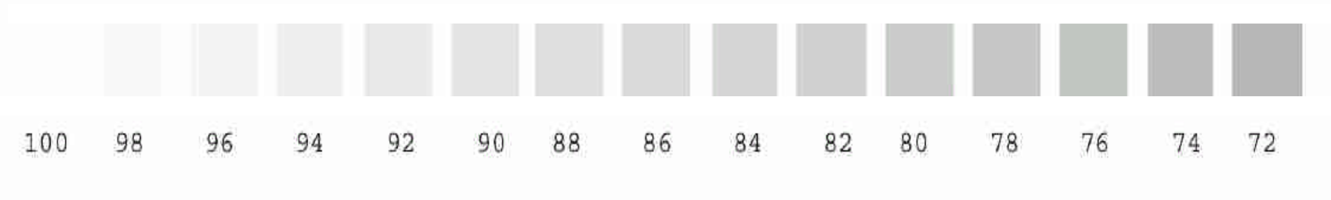
The use of actual biomedical imaging equipment for education, while desirable for real-life hands-on learning, is typically not feasible due to safety concerns, high cost, and lack of availability. It is possible to purchase for laboratory use small x-ray tubes similar to those used for x-ray based imaging techniques, but these start at about $2,000 without detection systems. This is too expensive for most educational programs. More critically, exposure to such sources of ionizing radiation is associated with a number of safety risks including serious skin burns[13] and increased cancer risks[14]. While biomedical imaging equipment abounds in the radiology departments of any major hospital, the availability of such equipment for learning purposes is extremely limited due to the requisite priority patient examinations have for the machines.

Materials and Methods

The basic approach of this work is to use a lamp with an incandescent light bulb to simulate an x-ray tube. Both the light bulb and an x-ray tube emit photons, albeit in vastly different energy ranges, that obey the principles of physics – traveling in straight lines, scattering, etc. The shadow cast on a paper "detector" when an object blocks visible light is analogous to the x-ray image developed when higher density tissues attenuate x-rays. Exploiting this analogy, a series of visible light exercises was developed to teach the principles of x-ray imaging. Using the incandescent bulb light source, pieces of transparency film, and a printed light intensity scale, students investigate in a semi-quantitative manner the relationship between attenuator thickness and image intensity. This exercise teaches students an important principle of x-ray imaging without exposing them to ionizing radiation and thus provides a safe and inexpensive alternative for hands-on learning suitable for college and advanced high school learners. Visible light is also used in specially designed exercises to teach the principles of magnification, penumbra, and detector resolution.

In the attenuation exercise, learners are first asked to discuss (1) how a shadow is like an x-ray image and (2) how they think the shadow of an object will change as the thickness of the object increases. They are then instructed to gather the following readily available supplies:

- bright lamp such as a desk lamp or reading light (but not a halogen lamp)
- aluminum foil
- one sheet of clear transparency film, cut into sections about 2.5"x 4"
- printed light intensity scale (see below)
- tape



The learners tape the light intensity scale to a wall and set up the lamp to shine on the scale. When ready, the learners take a piece of foil with a hole the diameter of a thick pencil or pen and place it over the lamp. (Learners are cautioned to not leave the foil on the lamp long while the lamp is on, as heat will be trapped and increase the risk of bulb breakage.) The learners then darken the room, hold up a piece of transparency film a few centimeters in front of the light intensity scale, and match the intensity of the resulting shadow with a square on the scale as shown below in Figure 1. After recording this intensity in a data table (Table 1), the learners then repeat this process with two sheets of transparency film, then three, and so on.

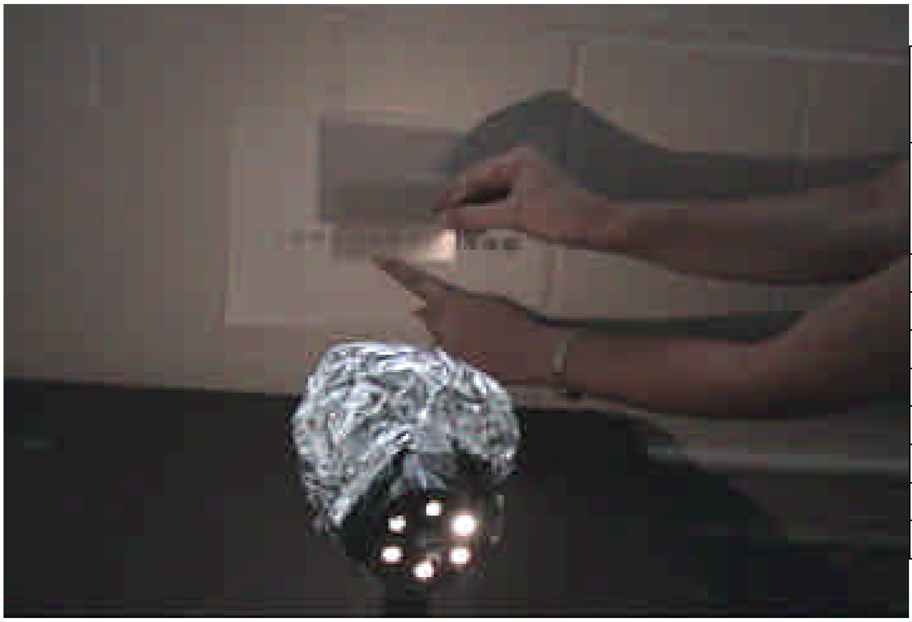


Table 1. Light attenuation exercise

Thickness (# of sheets)	Light Intensity (% white)
0	100
1	
2	
3	
4	
5	
6	
7	

Figure 1. Using visible light and transparency film to model attenuation of x-rays by an object

The learners are then asked to plot the natural logarithm of the shadow's light intensity versus the thickness of the attenuator for thicknesses 0 through 5 (or until values flatten completely) and to add a best fit line.

The learners are then asked to discuss several questions including the following:

- Do your data points fall along a relatively straight line? What does the equation of the fit line for your plot tell you about the relationship between attenuator thickness and the intensity of the shadow? (At some point during or after this discussion, learners conclusions are reinforced or corrected as needed by being informed of the basic relationship of Beer's law: $\frac{Intensity}{I_o} = e^{-m*Thickness}$)

- What is the attenuation coefficient, μ, of your transparency film? What are the units of μ?
- If the attenuator were infinitely thick, what would you expect the light intensity of the shadow to be?
- Why did the intensity of the shadow eventually stop changing and not approach 0 as the thickness of the attenuator was increased beyond about five layers? What might you change about the experimental set-up to get the shadows to approach 0% light intensity?
- In what ways are visible light photons like x-ray photons?
- In what ways are visible light photons different from x-ray photons?
- How is a shadow like an x-ray image?

These questions serve to draw out and clarify the students' understanding gained through completion of the exercise.

Visible light may also used to teach the principle of magnification. Using the same set-up as above, learners are directed to methodically vary the lamp to attenuator and the attenuator to "detector" (i.e., the surface upon which the shadow is cast) distances. The resulting data can be used to help learners discover the relationship between these distances and the degree of magnification. Appropriately cast questions help learners understand the ways the magnification effect can be beneficial or deleterious. Varying the size of the hole in the foil over the lamp can help students learn about penumbras and develop skill predicting their size. The similarities between visible light photons and x-rays can be exploited to teach additional principles of x-ray imaging in a safe and inexpensive manner.

Results

Two students in our biomedical engineering undergraduate program independently performed the exercise described. Their results, given here in Table 2 and plotted in Figure 2, demonstrate that this simple exercise works and is relatively reproducible despite its simplicity.

Table 2. Light attenuation exercise – Student Data

Thickness (# of sheets)	Student 1 Light Intensity (% white)	Student 2 Light Intensity (% white)
0	100	100
1	98	98
2	92	96
3	91	92
4	90	91
5	90	90
6	90	90
7	90	89

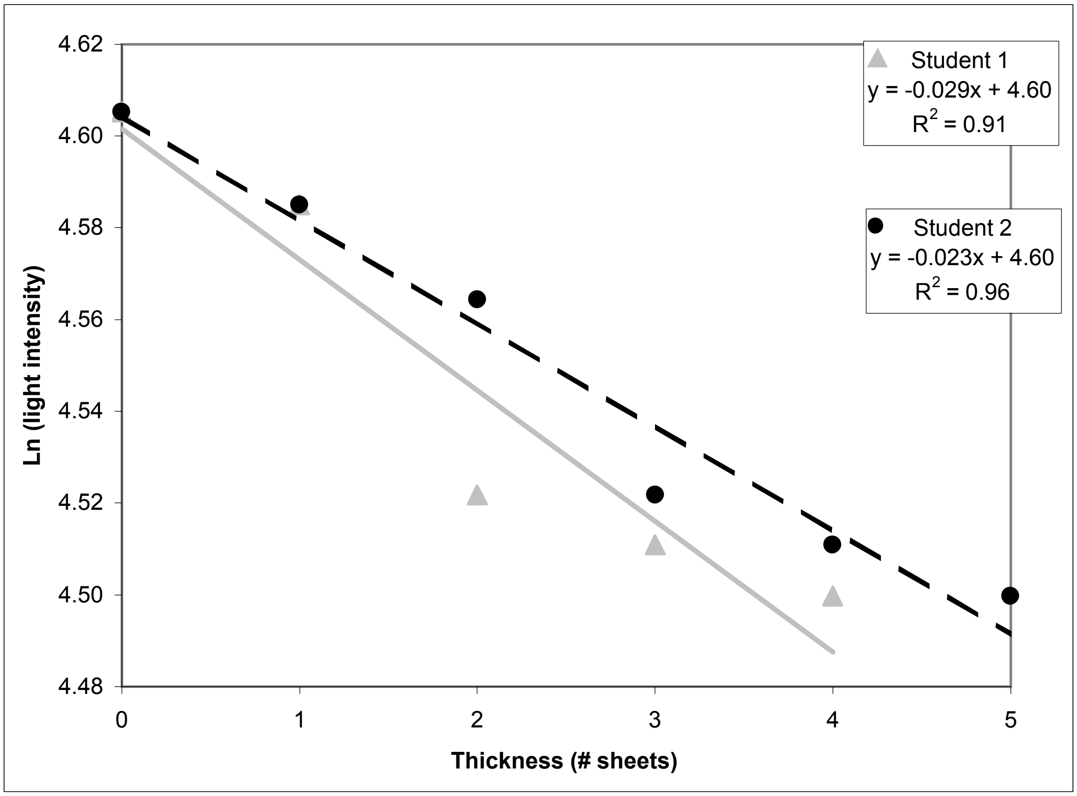


Figure 2. Plot of ln(light intensity) vs. attenuator thickness for data obtained by two different students. Note the strong correlations, which demonstrate the success of this hands-on exercise in illustrating Beer's law.

The astute learner does notice that the data flatten out. This observation is in conflict with the intuition brought out by the question regarding an infinitely thick attenuator. This contradiction helps motivate learning about scattered photons and about background signal. Appropriately constructed questions asked of the students help guide this learning.

Discussion and Conclusion

While Beer's law can be covered in a very short amount of lecture time such that learners can then see the mathematical relationship and even perform a basic calculation with it, performance of the described exercise and discussion of the questions provided is the type of activity shown to increase understanding and interest[1, 2, 9].

The difficulty in developing simple 'kitchen science' exercises such as this should not be underestimated. It is important to note that in each of these exercises, an accurate and safe model of the energy source for the given modality, such as visible light for x-rays or water waves for ultrasound, must be identified and tested. This is unlike other very successful 'kitchen science' programs[15] in which the actual physical phenomenon was safe to explore. It is surprising how many factors must be taken into consideration. For example, the absence of an aperture, provided in the attenuation exercise by the foil with a hole in it, on a light source with an effectively very large focal spot leads to penumbras so large as to dramatically change the apparent intensities of the shadows. Ideally, the exercise described would be much improved by using an even narrower, collimated light beam to illuminate only the piece of transparency film. However, doing so increases the complexity of the exercise set-up and reduces the number of photons from a simple light source such that the exercise can be difficult to complete.

The present state of imaging education is rapidly changing given the ease of electronic distribution of information. For example, excellent on-line biomedical imaging textbooks[16, 17] and tutorials[18, 19] now exist and numerous radiology teaching files can be found on the web[20, 21, 22, 23]. Manufacturers of medical imaging equipment have informative web sites with pictures of hardware and actual medical images[24, 25, 26]. Very successful hands-on general science educational activities for younger learners have been produced and published[27, 28] and abound at numerous science museums across the country.

Given the proven value of hands-on learning, exercises utilizing safe, inexpensive and yet accurate models, such as the x-ray attenuation exercise described in detail in this paper, are of strong value to departments with biomedical imaging curricula.

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Biographies

RACHAEL SHEVIN received a bachelor's degree in biomedical engineering from Vanderbilt University in May of 2002. She has worked on many different educational science projects including researching and constructing hands on lessons for middle school students, teaching at a camp to increase girls' interest in science, and designing and building an electronic pulse simulator for a museum.

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