

Teaching X-ray Imaging in the High School Physics Classroom: Safe, Hands-On and Inexpensive Instruction

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Hands-on



*Medical
Imaging*

A new hands-on curriculum developed at Vanderbilt University focuses on teaching medical imaging at the high school level as a means of both covering physics and mathematics content and engaging students in real-world applications of engineering and biomedical imaging. This curriculum was tested in the summer of 2004 on seven high school students. The testing revealed that the curriculum had a very positive impact on student interest in biomedical imaging and resulted in several improvements and additions to the curriculum. The curriculum, testing, and future plans are described in this paper.

Curriculum

Our goal is to construct a science curriculum that achieves the goals of K-12 sciences standards and introduces students to the exciting field of biomedical imaging. By early summer 2004, the research team developed a draft curriculum that focused on x-ray imaging and computed tomography (CT). The curriculum begins by presenting the learners with challenges that provide context and motivation for learning the material presented and opportunities to practice applying that knowledge. This approach is guided by research on human learning and its implications for instruction detailed in a recent National Academy of Science report called *How People Learn*¹. Specifically, the instruction is designed around “anchored inquiry” of interesting challenges^{2,3}. Students’ inquiry processes are guided by an instructional sequence built around a learning cycle called the ‘Legacy cycle’³. The learning cycle begins with a strongly contextually based ‘challenge.’ The challenge statement provides enough background information to stimulate students’ intuitions, build interest and generate ideas about what more they need to learn.

Careful selection of this challenge is critical to motivating the target student populations and preparing for a guided inquiry experience into the field of biomedical imaging.

The grand challenge used in the initial version of this curriculum was about a sumo wrestler (i.e., a very large person with extensive muscle and fat mass) who had a diving accident that may have caused injury to his spine. The challenge was to make an accurate diagnosis of the wrestler's condition. This challenge required learners to address issues related to production of an x-ray beam and the interactions of that beam as it traveled through such a large tissue mass, detection of x-rays, image characteristics including magnification and penumbra, resolution, and projections versus tomograms. Initial experience with this challenge as a motivating context was less than optimal because students did not find it compelling enough to learn more about. So, we replaced it with this grand challenge:

A 36-year-old female visits her doctor because she has been experiencing uncomfortable breathing and coughing. At first, she thought it was just a cold, but the problem has persisted for about three or four weeks. Her doctor, concerned by how long her symptoms have lasted, refers her to you, a radiologist. You initially order an x-ray. When the results come back, the x-ray shows an opaque mass within the chest cavity. Among the possibilities for the diagnosis is bronchial atresia.

How does x-ray imaging work?

Why does the mass show up in the image?

What can we do to make this mass appear more clearly?

How sure can we be about our diagnosis and what might make us reach an erroneous conclusion?

This initial grand challenge sets up a sequence of follow-on challenges that provide a context for learning about many imaging concepts such as specificity, accuracy of diagnosis, and tomographic imaging with computed tomography (CT). These challenges provide an orienting context for the laboratory experiments students perform to learn more about the details of the fundamental concepts of medical imaging.

The curriculum is provided in three parts – an instructor's manual, electronic slide presentations, and a student edition of the laboratory manual. The instructor's manual provides an overview of the curriculum, including the challenges and suggestions for how to engage the students in those challenges, and gives specific suggestions about the hands-on exercises. A list of materials needed is given at the start of each exercise. These materials are inexpensive and readily available at a variety of stores. The maximum allowed cost is \$25 per experiment, although most cost no more than a few dollars. This facilitates the use of this curriculum by learners in nearly any environment.

The first thing an instructor needs to do is to assess the students' baseline knowledge by administering the provided pretest quiz. Then, the instructor will present a challenge and guide the students through the process of generating ideas in response to the challenge. Next, the instructor presents the corresponding slide presentation. These presentations describe and illustrate the underlying physical and engineering principles that a learner needs to understand in

order to address the challenges. In addition, the presentations also introduce the hands-on exercises. The exercises can be performed in a variety of settings, although some of the experiments require a room that can be darkened and electrical outlets. The experiments are easier to perform if tables, counters, or laboratory benches are available on which to work. Ideally, groups of two or at most three students should collaborate to perform the experiments, although in many instances a learner can perform the experiments alone. The instructor should make and distribute copies of the student edition of the laboratory manual, which includes detailed directions for the hands-on exercises. After the exercises are completed, the instructor administers the post-activity quiz, which is also included along with answer keys for all quizzes. Finally, the instructor leads the students in a “Go Public” stage of the Legacy Cycle in which the students have an opportunity to communicate what they learned.

Thirteen imaging education exercises were included in the laboratory manual and an additional seven to ten exercises, prompted in large part by ideas from the high school students involved in the testing, are under development. The thirteen exercises currently included in the laboratory manual are listed in the table below.

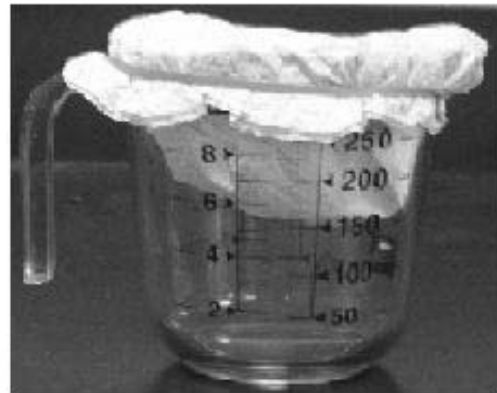
Table 1. Imaging Education Exercises Tested in 2004.	
Exercise	Concept(s) Taught
Compton Scattering	X-ray interaction via Compton scattering; image noise; safety
Water Attenuation Experiment	Attenuation as a function of amount of attenuating material present
Visible Light Experiment	Attenuation of photons as a function of # of thicknesses of transparency present; gray scales; Beer's law
Grids	Use of grids to reduce scatter; effects of changing grid characteristics on image
Intensifying Screen	Amplification of x-ray signal by conversion to multiple lower energy photons
“Silver” Ions	Detection via film; image development
Water Experiment: Digital Detector	Pixelated appearance of digital images
Water Experiment: Pixels And Resolution	Effect of pixel size on spatial resolution
Apple Experiment: Detector Resolution/Pixels	Effect of pixel size on spatial resolution (more in depth than water experiment)
Apple Experiment: Focal Spot Effects	Penumbra (geometric unsharpness); photon fluence
Apple Experiment: Magnification And Penumbra	Magnification and penumbra
Clinical Diagnosis	True/false positives & negatives, sensitivity, specificity, accuracy
Computed Tomography	Computed Tomography

The visible light experiment, which utilizes visible light and layers of transparencies to demonstrate the concept of attenuation and its relation to properties of the attenuator (the number of layers in this case) as described by Beer's law, was described in an earlier ASEE presentation⁴. Three more of these exercises are briefly described here in this paper. These are the water attenuation experiment, the clinical diagnosis experiment, and the grid experiment.

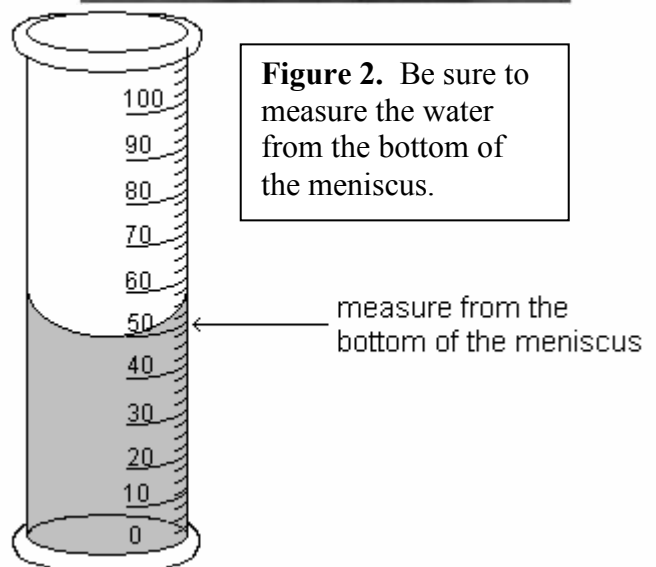
Like the visible light attenuation experiment, the water attenuation experiment, developed and tested in 2004, demonstrates the concept of attenuation and its relation to properties of the attenuator. The exercise illustrates how attenuation of x-ray photons is related to the thickness of the attenuating medium. In this exercise, a stream of water represents a beam of X-ray photons, and a thickness of paper towels represents the attenuating medium. Before doing anything, students are asked to provide their initial thoughts, an activity that helps them draw on their intuitions and develop a hypothesis for the relationship between how water is absorbed by the towels and how human tissue absorbs x-ray energy. To organize and prompt their thoughts, these two questions are asked: "What effects do you think a thicker medium will have on attenuation?" and "How will this affect the image?"

As with all the experiments in this curriculum, ordinary objects of very minimal cost are used. For this water attenuation activity, the materials are one roll of paper towels, one gallon of water, a 100ml graduated cylinder, one measuring cup (1 cup size), and one rubber band.

Figure 1. This is how the paper towel should be set up in the measuring cup. Note how the towel dips down into the cup to prevent water spillage.



The experimental method is described as follows: Set up the measuring cup with a paper towel around the top, secured with a rubber band, making sure the paper towel dips down into the cup slightly (Figure 1). Measure out 50.0 mL of water with the graduated cylinder, and pour the water through the paper towel into the measuring cup. Wait until all the drops of water have gone through the paper towel layer. Then carefully take off the rubber band and paper towel (do NOT squeeze any of the paper towel's water back into the cup). Pour the water from the measuring cup back into the



empty graduated cylinder and measure how much water (in mL, to the nearest tenth of an mL) went through the paper towel. Be sure to measure from the bottom of the meniscus, as shown in Figure 2. Record this value in Table 2. Do another trial with a thickness of one paper towel, using a fresh paper towel from the same roll of towels used previously. If residual water remains in the measuring cup from the last trial, you can dry it with a paper towel. Make sure the towel dips into the cup the same amount as before. Record your second trial (measured in the graduated cylinder in the same manner) in Table 1. Average the two trials' values and record them in Table 2, too. Don't forget to record tenths of milliliters. Repeat this for thicknesses of 2 and 4 paper towels, performing two trials for each thickness. Also average these and record all these values in Table 2.

# of Towels	Trial 1	Trial 2	Average
1			
2			
4			

Table 2. Record the amount of water than went through the paper towel here. Average the two values for each thickness and record that, too.

The lab can stop here, at which point the students are asked some reflection questions: (1) How is thickness related to attenuation and how does this relate to photon absorption? (2) How is this lab set-up similar to what actually happens in a radiograph? (3) How is this lab

set-up different from what actually happens? (4) What do you think would happen if a washcloth were used, rather than a paper towel? What does this say about attenuation as it relates to a specific attenuating medium?

Alternatively, depending on the students' level of mathematical training, they can be asked to take the natural logarithm of the ratio of the average amount of water passing through the paper towels (last column of Table 2) to the amount of water poured in (50.0 mL) and then plot that versus the number of paper towels used. The slope of the best fit line for those data points defines the "linear" attenuation coefficient of the paper towels. Of course, with only three points, such a plot is not highly illustrative of the Beer's Law relationship between the "thickness" of the attenuator and the amount of "beam" that is attenuated. The visible light experiment⁴ is better for revealing that relationship yet the present (water) experiment does help to demonstrate in a more directly observable manner the removal of photon analogs (i.e., water molecules) from the "beam."

Another hands-on exercise, the clinical diagnosis experiment, helps students learn about sensitivity, specificity, and overall accuracy when x-ray images are read by a radiologist. In this exercise, learners are presented with twenty-four rectangles with each rectangle filled in by a shade of gray. The learners are asked to decide for each rectangle whether it is darker or lighter than a reference rectangle. "Darker" is interpreted as "diseased" or positive, while "lighter" is interpreted as "not diseased" or negative. Students are then given a key against which to compare and categorize their answers as true positive, false positive, true negative, or false negative. The difficulty often encountered by the students in making these decisions is analogous to the figurative and literal "shades of gray" a radiologist is forced to interpret in x-ray images. This exercise helps students to understand an important engineering and human factors aspect of medical imaging – that results can be ambiguous, difficult to interpret, and subject to

human error. The calculations and questions through which the students are guided help drive home the strengths and limitations of imaging modalities in a quantitative and interactive manner.

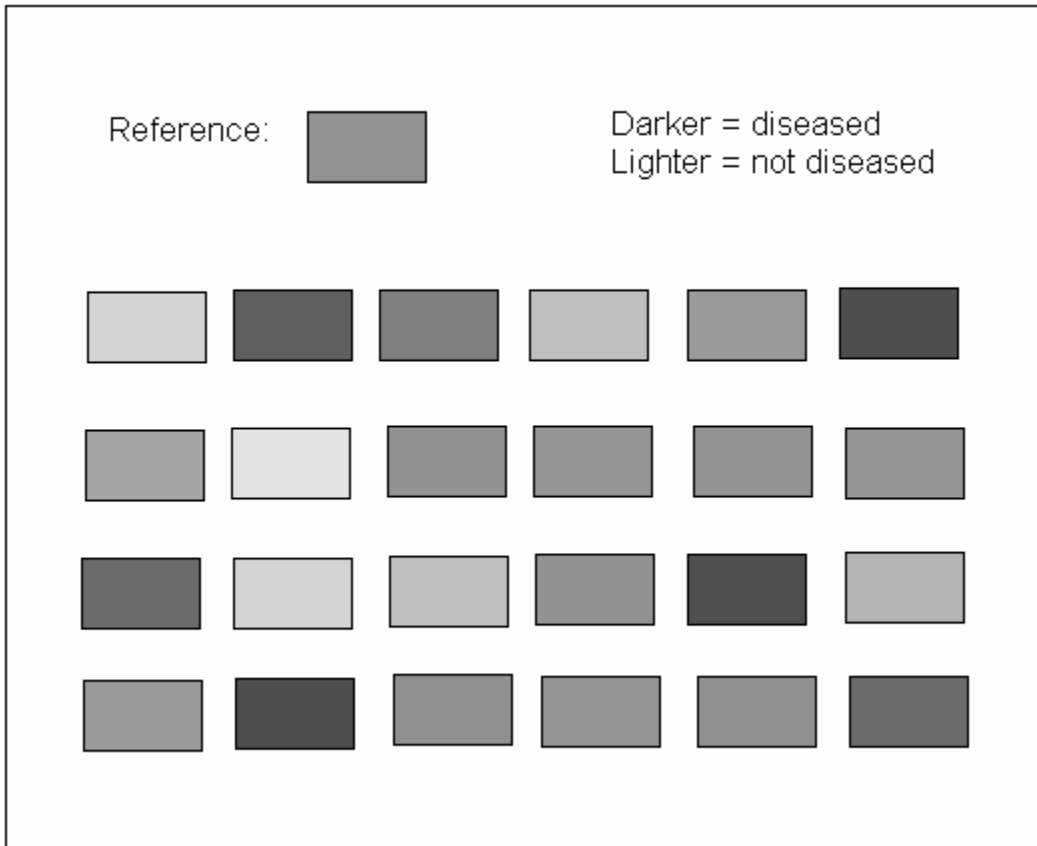


Figure 3. Clinical diagnosis decision diagram. In this exercise, learners have to judge whether or not each block is darker than or lighter than the reference block. As with real-life diagnostic situations, in this exercise it is sometimes very difficult to accurately determine relative darkness. The students' results are compared to actual results to arrive at the number of true and false positives and true and false negatives.

The students in the summer 2004 test group generated ideas for a simple hands-on exercise to help students learn about the importance of moving an anti-scatter grid during an x-ray exposure. The experiment requires two pieces of solargraphic paper, two coins of the same type, and two pieces of screen with coarse holes. A coin and a piece of screen are placed on one piece of the solargraphic paper, which is then placed in sunlight. The second coin is placed on the second piece of solargraphic paper, which is also placed in the sunlight. The experimenter then places the screen over the paper such that it casts a shadow but moves the screen continuously throughout the exposure. When the papers are developed, a process that requires only water, the first paper will have an image of both the coin and the screen while the second paper will have only an image of the coin. This experiment illustrates the importance of moving grids during x-ray exposures. A companion experiment involving paper, rulers, and pencils illustrates the actual function of grids in limiting the amount of scattered radiation that reaches a detector.

Other hands-on exercises currently in the curriculum include new and/or improved exercises to teach about Compton scattering, intensifying screens, digital detection, pixels and resolution (multiple experiments), aperture effects, magnification, penumbra, CT projections and back projection reconstruction. The process used to develop these exercises can be briefly described as a six step process – identify learning objectives, brainstorm ideas for experiments, test these ideas, teach the best ideas to a small group of learners, let the learners try the experiments, and then gather feedback. This process, especially the last two steps, helps spawn new ideas for imaging education.

This curriculum meets numerous National Science Education Content Standards (A,B,C,E,F,G). Students are provided with an opportunity to do scientific inquiry through the challenge based curriculum. Extensive coverage is given to Content Standard B for Physical Science that includes the structure of atoms, structure and properties of matter, chemical reactions, motion and forces, conservation of energy, and interactions of energy and matter. Content standard C is addressed through a study of matter and energy in living systems. Students' understandings about science and technology (Content Standard E), science as a human endeavor, the nature of scientific knowledge, and historical perspectives (Content Standards G) are increased through this curriculum. Students also increased their understanding of personal and community health and natural and human-induced hazards (Content Standard F).

By using this challenge based curriculum, teachers are able to better meet the NSES Teaching and Assessment Standards as well. Teachers adapt curricula to meet the interests, knowledge, understanding, abilities and experiences of their students (Teaching Standard A) and engage in on-going assessment of multiple modalities of their students' understanding (Teaching Standard C). As Teaching Standards B and E direct, teachers support, guide, and facilitate student learning in a rigorous, but nurturing environment. Students have the opportunity to engage in an extended investigation and are provided a safe environment in which to do so (Teaching Standard D).

The assessments provided in this curriculum are consistent with the decisions they are designed to inform (Assessment Standard A) and are authentic in nature (Assessment Standard C). Extensive effort has been made by the researchers and the high school students to remove any type of bias present in the assessments to ensure fairness (Assessment Standard D).

The curriculum also meets numerous AAAS Project 2061 benchmarks, particularly those relating to Physical Health, the Designed World, and the Physical Setting. The Physical Setting's substandards of The Structure of Matter, Energy Transformations, and the Forces of Nature are addressed thoroughly in this curriculum. Additionally, the Health Technology and Communication areas of the Design World standards are addressed here.

Evaluation

Seven high school juniors and seniors were invited to work on a paid basis with the project team 30 hours/week for a period of two weeks. Prospective participants were informed of the project by their science teachers and were required to fill out an application form that included a brief essay. Selection was based on student essays and teacher recommendations. No information

about the students' academic standing or grades was requested or used in selection of participants. Both public (N= 4) and private (N=3) school students were selected. There were three female, four male, one African-American, one Pacific Islander, and one Asian/Caucasian participants.

The high school students were given pre- and post-workshop surveys to evaluate changes in interest and attitudes towards biomedical imaging in particular and biomedical engineering in general. They tested each portion of the materials, including the many hands-on activities and content quizzes. The students worked primarily in groups of two or three, with groups changing on a daily basis.

The high school students provided the team not only with extensive feedback but also new activities that covered additional topics within the curriculum. This unique combination of student feedback and authorship provided an excellent means of field-testing the materials prior to actual large-scale field testing in the spring and fall of 2005.

Comparison via paired t-tests for means of pre- and post- survey results indicated an increase in student interest in biomedical engineering (BME) in general ($p < 0.1$) and biomedical imaging (BMI) in particular ($p < 0.002$). Students reported an increase in their enjoyment of learning science ($p < 0.02$). Students also reported increased understanding of what BME ($p < 0.01$) and BMI are ($p < 0.001$). It is noted that statistical tests on a sample size of only seven are not highly robust. Nonetheless, in addition to these increases in quantitative metrics of interest in BME and BMI, survey results demonstrated that the two week experience dramatically increased the verbal fluency and intellectual richness of the students' textual responses to questions about these domains.

Future Plans

This method of instruction and the collection of challenges and experiments described here are being tested in the spring 2005 semester in three different high schools. There are 70 students using the curriculum in two public high schools in Middle Tennessee and a smaller number of students using the curriculum in a private high school also in Middle Tennessee. Instructors in those courses are administering pre- and post-test assessments of learner competency with the skills and concepts being taught as well as an attitude assessment about BMI, BME, and science in general. Comparison of pre- and post-test results will help determine the impact and effectiveness of these lessons. In addition to the high school testing, the material is also being tested in an undergraduate course at a college in Massachusetts. Additional test beds are being recruited.

In the summer of 2005, a new test group of high school students will beta test hands-on exercises designed to teach the principles of nuclear imaging and ultrasound.

Conclusion

A safe, hands-on and inexpensive curriculum for teaching x-ray principles developed for and tested with high school learners successfully stimulated interest in biomedical imaging and

biomedical engineering among the test population. High school learner participation in testing aided the development of the curriculum and provided new ideas for learning activities.

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Biographical Information

CHRISTOPHER D. GARAY – Mr. Garay is a junior in biomedical engineering at Vanderbilt University. He was one of three undergraduates who conducted the beta testing and developed the project in the summer of 2004. Mr. Garay is again working on this project, developing a new set of exercises to teach about x-ray interactions.

AUBREY A. HUNT – Ms. Hunt is a junior in biomedical engineering at Vanderbilt University. She was one of three undergraduates who conducted the beta testing and developed the project in the summer of 2004. Ms. Hunt has continued to work on the project, developing presentation materials and lab manuals and preparing experiments for distribution.

STEPHEN M. SCHLEICHER - Mr. Schleicher is a senior in biomedical engineering at Washington University. He was one of three undergraduates who conducted the beta testing and developed the project in the summer of 2004.

SEAN P. BROPHY – Dr. Brophy is the co-leader of the Learning Sciences group in an NSF Engineering Research Center called VaNTH. He conducts research on how undergraduate biomedical engineering students learn and how to design effective learning environments and assessments to enhance the potential of students' learning.

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