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Biomedical Imaging Education: Safe, Inexpensive Hands-On Learning*

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In an effort to improve the quality and quantity of hands-on educational materials for science and engineering classrooms, a series of curriculum units teaching concepts from medical imaging, specifically x-ray and computed tomography, at levels appropriate for both high school and undergraduate classrooms has been developed. The Legacy cycle-based materials pair traditional lectures with interactive hands-on activities that are both safe and inexpensive. The curriculum unit is divided into four sections, each focused on a different challenge and assessed with a quiz given to students pre- and post-instruction. An example from one unit is provided. Using within participant paired t-tests of pre- and post-quiz scores; the curriculum has been shown to significantly improve students' understanding of medical imaging at various grade levels. Analysis of student surveys taken by students before and after implementation shows this instructional method can also improve students' perception of their own math and science performance and raise their awareness of what professional biomedical engineers do.

Keywords: biomedical imaging; challenge; x-ray radiography; K-12; undergraduate

1. INTRODUCTION

A NEW CURRICULUM being developed focuses on teaching medical imaging at the high school and undergraduate levels, as a means of both covering physics and mathematics content and engaging students in real-world applications of engineering and biomedical imaging. A curriculum unit focusing on x-ray imaging and computed tomography (CT) was developed first and is the subject of this article.

The goals of this work were to construct a safe, inexpensive, and hands-on curriculum unit utilizing challenge-based instruction that achieves K-12 science and undergraduate engineering accrediting standards and introduces students to the field of biomedical imaging. Another goal of the work was to evaluate the impact of the unit on students' learning of science/engineering concepts and perceptions of biomedical engineering as a career option.

The curriculum unit begins by presenting the learners with a grand challenge that provides context and motivation for learning the material presented in the unit and opportunities to practice applying that knowledge within multiple contexts. This approach is guided by a National Academy of Science report *How People Learn* [1] which synthesizes current theories of knowing and effective instruction informed by these theories. Specifically, the instruction is designed around 'anchored inquiry' of interesting challenges [2, 3]. Students' inquiry processes are guided by a learning cycle called the 'Legacy cycle' [4] that 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. Judicious selection of the challenge can increase its appeal to a broader range of potential biomedical engineers including more minorities and women.

The low cost and safe nature of these hands-on exercises and challenge-based learning activities make these exercises accessible to learners in nearly any environment, thus increasing the breadth of impact for this project. Careful design of learning activities that build on these hands-on exercises will help students comprehend the fundamental engineering principles associated with the process of imaging. As with all the experiments in this curriculum, ordinary objects of very minimal cost are used. The maximum targeted cost is $25 per experiment, although most cost no more than a few dollars. This facilitates the use of this curriculum by learners in settings where more expensive activities are not feasible.

1.1 Hands-on learning

A number of studies have been conducted over the last twenty years exploring the differences in student learning styles, prior experiences and their academic achievement at various levels of educa-

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tion, economic status and regions of the country. Learning preferences are often categorized into one of four main categories: auditory, visual, tactile or kinesthetic. From these studies, it has been shown that when students at any level of education are taught according to their preferred learning style, their attitudes towards the subject as well as short and long term achievement in the covered material significantly improve [5]. Specifically in the sciences, further study has been conducted in an effort to determine what makes experimental learning effective [6]. In undergraduate engineering curricula, hands-on design courses have been proven to engage students successfully, helping them draw connections between textbook knowledge and real world situations; however, their costs are typically very high [7, 8]. Currently in undergraduate medical imaging classrooms, the extent of hands-on learning materials is very limited due to obvious cost and safety limitations. Computer simulations have been developed by other educational research teams, but require teaching facilities to have computers and often internet connections [9]. Additionally, the simulations do not provide the hands-on experience many tactile learners often need. The hands-on high school and undergraduate educational materials developed in this project strive to appeal to students from each of the four learning styles by pairing traditional oral/auditory and visual lectures with inexpensive hands-on activities that provide tactile and kinesthetic experiences. The combination of these modalities provides learners with multiple sources of information. The physical hands-on materials support their noticing of the spatial relationships of components in the devices and the formalism of the vocabulary and governing principles are communicated through the oral narratives needed to communicate their explanation for how the devices work.

In summary, hands-on activities coupled with formal instruction provide learners with the opportunity to sustain their inquiry and attention on the multiple factors governing the behavior of an engineered system like a medical imaging device. The exploration can help illustrate how things work and formal instruction provides the language and principles that further explain and help students communicate what they have learned.

1.2 Legacy cycle instruction

The Legacy Cycle's contextually based 'Challenge,' discussed above, is followed by a sequence of instruction where students attempt to 'Generate Ideas' (first thoughts on the challenge), view 'Multiple Perspectives' of experts and others commenting on the challenge and possible ways to address it, participate in extended 'Research and Revise' activities where data and information are gathered to help the student address the challenge, followed by 'Test your Mettle'—a formative self-assessment. These stages are at the heart of the hands-on experiments and lectures students will experience as they further construct their understanding of the governing principles of imaging. The final stage called 'Going Public' is when students' synthesize what they have learned to generate solutions they communicate with their peers and others. For our experiments, this synthesis occurs as part of a post instruction quiz. The Legacy Cycle design has been successfully implemented for engineering education in the college classrooms [10–16] and the middle and high school science classroom [17–21].

2. METHODS

2.1 New imaging instructional materials

Medical imaging, specifically x-ray and computed tomography modalities, create the background for the entire unit discussed in this paper. Under the context of x-ray and CT in this instructional unit, students seek to answer the following grand challenge question:

> 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?

With students now engaged in the situation, they are then prompted to generate ideas about what they need to learn in order to respond to this grand challenge. As students think about the grand challenge, they are given an opportunity to share their own background knowledge and determine for themselves what they will need to learn in order to be successful. After initial ideas have been explored, the instructor can move into the first of four units pairing traditional lectures with hands-on activities for learning X-ray and CT concepts. These four units are designed to investigate big ideas associated with solving the grand challenge. These units are centered on the four driving questions that each begin a different Legacy Cycle.

Challenge #1: How do different materials interact with x-rays and how does this create image contrast?

Challenge #2: How is an x-ray image created?

Challenge #3: What are the characteristics of an ideal x-ray image? How can you describe these characteristics?

Challenge #4: What other imaging modality would allow a better look at the mass? How does this modality use an x-ray to get a different image?

Included in the curriculum unit was an instructor manual, electronic slide presentations for lectures and student manuals that included lab instructions. During implementation, instructors were welcome to contact the authors for any additional assistance, though no formal training of the instructors was provided. Differences between the high school/college freshmen level materials and the undergraduate junior/senior level materials were very few and included the addition of modulation transfer functions for the advanced learners. In actual application, the materials formed the entirety of the framework for the educational unit at the high school/college freshman level while, at the undergraduate junior/senior level, they were utilized as components of a much larger and more complex educational unit.

Thirteen hands-on activities were developed for the unit. They are listed with concepts they cover in Table 1. The activities explore concepts such as Beer's law and attenuation, signal amplification and detection, and image characteristics. Some activities are described in more detail in other manuscripts [22, 23] and one is presented below.

2.2 Sample activity: apple experiment—focal spot effects

The Apple Experiment: Focal Spot Effects activity was created to teach students about penumbra or geometric un-sharpness and contrast. Students are reminded that an x-ray tube emits x-rays from a focal spot with a finite size. In this lab, students explore what effects changing the focal spot had on the image. In order to effectively model changing the focal spot of a lamp, students create a cover of aluminum foil with a hole that will restrict the area from which light is emitted. 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 the shadow and the changing focal spot.

As with all the experiments in this curriculum, ordinary objects of very minimal cost are used. For this focal spot effects activity, the materials are a desk lamp, light bulb, aluminum foil squares, an apple (real or fake), graph paper of two resolutions, masking tape, and a marker. This equipment totals approximately $13.50.

The experimental method is described as follows: Create two apertures for the light source with sheets of aluminum foil, one with a small diameter hole, about 5 mm, and a second with a large diameter hole, about 10 mm. These apertures will model changing the focal spot size, which will change the size of the region from which the photons originate, and in this example, will change the total number of photons in the beam. Focal spot size is very important in radiography and is a property of the design of the x-ray tube.

Tape a piece of the large graph paper (4 squares per inch) on the wall behind the apple. This will be the coarse detector. Shine the lamp on the apple, playing with the setup to get a good apple shadow on the coarse detector. Look at the shadow without the focal spot. Now, place the large (10 mm) aperture on the lamp head (See Fig. 1). How has the relative darkness of the shadow compared to the brightness of the background changed? This is called image contrast. An *increase* in contrast denotes an *increase in the difference* between light and dark areas. How has the band of intermediate, fuzzy darkness on the edge of the image changed? This blurred area is known as the image penumbra.

Now, keeping the large aperture on the lamp, trace the discretized outline of the apple on the detector. Repeat for the fine detector (graph paper, 5 squares per inch).

Next, change the aperture on the lamp to the small (5 mm) focal spot. Put a fresh coarse detector on the wall as before, and obtain a shadow again. Trace the outline of the apple on the detector. Repeat for the fine detector. Compare these two sets of images.

The lab can stop here, at which point the students are asked some reflection questions: (1) Can you tell which method is best: without an aperture, with the large (10 mm) aperture, or with the small (5 mm) aperture? (2) How does applying the focal spot affect your ability to see the apple's stem? (3) How does pixel size (4 or 5 squares per inch) affect the ability to resolve, or distinguish fine detail of, the apple? (4) How does effective focal spot size affect contrast and penumbra? The experiment has proven to be easy to accomplish with consistent results. The reflection questions are essential to help students tie the hands-on activities back to the actual engineering systems. The reflection activity illustrates a type of 'Test your mettle' and 'Go Public' activity to provide some closure on the hands-on activity they conduct as part of their research. The teacher can use the students' reflections as a discussion starter, which can provide students with some level of feedback on their current understanding of the content related to the challenge.

2.3 Standards met

The curriculum unit meets National Science Education Content Standards A, B, C, E, F, and G used in K-12 education [22]. The challenge based lessons provide students with an opportunity for scientific inquiry (Content Standard A). The structure of atoms, structure and properties of matter, conservation of energy and interactions of energy and matter are all addressed extensively throughout the four units (Content Standard B). The study of matter and energy in living systems is addressed fulfilling Content Standard C. Additionally; the

Table 1. Hands-on activities included in curriculum unit with concepts taught and relevant high school science standards and undergraduate ABET accreditation outcomes

Exercise & Challenge#	Concept(s) Taught	High School Science Standards	Accreditation Outcomes
Compton Scattering (Challenge 1)	X-ray interaction via Compton scattering; image noise; safety.	B. Conservation of momentum and energy; interactions of energy and matter. F. Natural and human-induced safety hazards.	A. an ability to apply knowledge of mathematics (probability), science (physics), and engineering (noise, safety).
Water Attenuation Experiment (Challenge 1)	Attenuation as a function of amount of attenuating material present.	B. Structure of atoms; structure and properties of matter. C. Matter, energy, and organization in living systems.	A. an ability to apply knowledge of mathematics (exponential decay functions). B. an ability to conduct experiments, as well as to analyze and interpret data.
Visible Light Experiment (Challenge 1)	Attenuation of photons as a function of # of layers of transparency present, gray scales, Beer's law.	B. Structure of atoms; structure and properties of matter; interactions of energy and matter. C. Matter, energy, and organization in living systems.	A. an ability to apply knowledge of mathematics (exponential decay functions) and science (photon attenuation). B. an ability to conduct experiments, as well as to analyze and interpret data.
Grids (Challenge 2)	Use of grids to reduce scatter, effects of changing grid characteristics on image.	E. Understanding science and technology. F. Natural and human-induced safety hazards.	A. an ability to apply knowledge of mathematics (geometry). B. an ability to conduct experiments, as well as to analyze and interpret data. C. an ability to design a component to meet desired needs within realistic constraints such as health and safety.
Intensifying Screen (Challenge 2)	Amplification of x-ray signal by conversion to multiple lower energy photons.	B. Structure of atoms; structure and properties of matter. .	A. an ability to apply knowledge of science (physics) and engineering (principles of amplification). B. an ability to conduct experiments, as well as to analyze and interpret data.
'Silver' Ions (Challenge 2)	Detection via film, image development.	B. Structure of atoms; structure and properties of matter. .	A. an ability to apply knowledge of science (chemistry) and engineering (attenuation). B. an ability to conduct experiments, as well as to analyze and interpret data.
Water Experiment: Digital Detector (Challenge 2)	Pixelated appearance of digital images.	E. Understanding science and technology.	A. an ability to apply knowledge of engineering (digitization). B. an ability to conduct experiments, as well as to analyze and interpret data.
Water Experiment: Pixels and Resolution (Challenge 3)	Effect of pixel size on spatial resolution.	E. Understanding science and technology.	A. an ability to apply knowledge of engineering (digitization, spatial resolution). B. an ability to conduct experiments, as well as to analyze and interpret data.
Apple Experiment: Detector Resolution/ Pixels (Challenge 3)	Effect of pixel size on spatial resolution (more in depth than water experiment).	E. Understanding science and technology.	A. an ability to apply knowledge of mathematics (geometry) and engineering (digitization). B. an ability to conduct experiments, as well as to analyze and interpret data.
Apple Experiment: Focal Spot Effects (Challenge 3)	Penumbra (geometric unsharpness), photon fluence.	E. Understanding science and technology.	A. an ability to apply knowledge of mathematics (geometry). B. an ability to conduct experiments, as well as to analyze and interpret data. C. an ability to design a component to meet desired needs.
Apple Experiment: Magnification and Penumbra (Challenge 3)	Magnification and penumbra.	E. Understanding science and technology.	A. an ability to apply knowledge of mathematics (geometry). B. an ability to conduct experiments, as well as to analyze and interpret data. C. an ability to design a component to meet desired needs.
Clinical Diagnosis (Challenge 3)	True/False positives & negatives, sensitivity, specificity, accuracy.	E. Understanding science and technology. F. Personal and community health. G. Science as a human endeavor.	A. an ability to apply knowledge of mathematics (computation, validation). B. an ability to conduct experiments, as well as to analyze and interpret data. F. an understanding of professional and ethical responsibility.
Computed Tomography (Challenge 4)	Computed Tomography.	E. Understanding science and technology. G. Science as a human endeavor.	A. an ability to apply knowledge of mathematics (projection & dimensions) and engineering (back projection). B. an ability to conduct experiments, as well as to analyze and interpret data.

materials develop the student's understanding of science and technology (Content Standard E), and addresses science as a human endeavor and historical perspectives (Content Standard G). Personal and community health as well as natural and human-induced hazards are also addressed through the grand challenge, and when studying radiation dosage (Content Standard F).

Additionally, the curriculum unit meets aspects of the Accreditation Board for Engineering and Technology (ABET) criteria for accrediting baccalaureate programs [23]. Criterion 3 Program Outcome (A), requiring the application of math, science and engineering, is strongly emphasized throughout the four units. Experiments are conducted and data are analyzed and interpreted through the hands-on activities, fulfilling Program Outcome (B). Experience with the impact of design choices on imaging results helps students achieve Outcome (C). Outcome (F) is also briefly addressed concerning the responsibilities of radiologists to ensure accurate images are obtained and through discussion of true and false positive and negative diagnoses. All activities typically involve teamwork [Outcome (D)], though not necessarily with interdisciplinary teams, and, through 'Going public,' exercise students' abilities to communicate effectively [Outcome (G)]. Aspects of the specific criteria for biomedical engineering programs that require students to demonstrate an understanding of biology and physiology, solve problems at the interface of engineering and biology, and address issues associated with the interaction between living and non-living materials and systems are also included throughout the unit.

2.4 Hypothesis

The hypothesis of this work is that use of this curriculum unit not only improves students' knowledge of the mechanics behind x-ray and CT, but also expands their understanding of biomedical engineering and medical imaging as exciting fields and potential areas for future study and careers.

2.5 Experimental design to evaluate the impact of the curriculum unit on students

The curriculum unit underwent beta testing in the summer of 2004 when seven high school juniors and seniors worked as testers on a paid basis 30 hours a week for two weeks. From the feedback generated during the two weeks of testing, the curriculum unit was improved and then offered to high school and undergraduate classrooms for further study.

During the spring of 2005 (n = 46) and again during the 2005–2006 school year (n = 46), four high school science teachers incorporated the curriculum unit into their teaching. These schools included one private school in Tennessee, two public schools in Tennessee, and one public school in New York. Additionally, the curriculum unit was taught at Vanderbilt University as a freshman seminar course (n = 17) as well as at Vanderbilt University (n = 60) and Western New England College (n = 15) as part of an upper-level biomedical engineering elective for students of junior and senior standing.

In order to evaluate how effective the developed curriculum unit was in conveying x-ray and CT concepts to students, four quizzes were administered at each of the three education levels before and after teaching through the four challenges. Participation in each quiz is shown for each level in Table 2. Paired t-tests for means were conducted evaluating the change in student performance. An example of a question asked of students in the first unit is as follows:

You take an x-ray image of two objects, both made of the same material. The first object is a cube that is 1.0 cm along each side. The second object is a plate 5.0 cm x 2.0 cm x 0.10 cm, laid flat on the x-ray table.

Put a checkmark next to the correct statements:

_____ both objects have the same attenuation coefficient

_____ the objects are equally likely to attenuate an incident x-ray

_____ the cube is more likely to attenuate an incident x-ray than is the plate

_____ the plate is more likely to attenuate an incident x-ray than is the cube

The grading rubric for each question was developed by a medical imaging expert and reviewed by another medical imaging expert and a learning science expert. The rubrics were then used by four graders on a small group of quizzes. The scoring of these papers was reviewed collectively and then minor adjustments were made in the rubrics where needed to achieve complete agreement on scoring of the quizzes. These rubrics were then used to score all quizzes.

2.6 Attitude surveys

An attitude survey, shown in Appendix 1, was given to all high school and freshman participants prior to beginning the curriculum unit (pre-survey) and immediately following its completion (post-survey). Because of the nature of the survey questions, with an emphasis on high school courses and interest in entering engineering programs, the authors chose not to administer the survey at the junior/senior undergraduate level. This survey asked forty-four questions about participant's attitudes towards their ability to utilize mathematical and problem solving skills, their concepts of what engineers are like, their opinions of engineering as

Table 2. Number of Participants on each quiz at each level of student

	Quiz 1	Quiz 2	Quiz 3	Quiz 4
High School	92	69	70	60
Freshman	17	15	16	15
Junior/Senior	15	72	15	15

a field, opinions about themselves, and their opinions about their performance in physics courses. Participants were asked to rate their agreement with the given statements on a Likert scale of 1, very strongly agree, to 6, very strongly disagree for all but the section on their performance in physics which used a 5-point Likert scale. Survey content validity was established through a formal expert review. As a measure of survey reliability, Cronbach's alpha [24] was calculated for each of the five attitudes and was found to be at least 0.7 for all attitudes, with most over 0.8. This survey was utilized to assess possible attitude change in student participants as stated in the goals and hypotheses of this study. Each of the attitudes being assessed is related to improved instructional materials and methods to better meet the National Science Education Standards and ABET criteria.

3. RESULTS

3.1 Instructional materials

By design, all activities cost less than \$25 per group of students. Most experiments were much less than that, approximately \$7 per group. A total of 13 experiments on x-ray imaging and CT were developed along with an additional 25 experiments covering major curricular units on ultrasound, radionuclide imaging, and magnetic resonance imaging. These materials can be found at http://engineering.vanderbilt.edu/BiomedicalEngineering/BiomedicalIimagingEducation.aspx.

3.2 Quizzes

Figures 1 through 4 show the results on each of the four quizzes, allowing for comparison among groups and between pre- and post-test performance. Fig. 5 shows percent improvement from the pre-test to the post-test for all quizzes. Performance improved significantly ($p < 0.001$) at each education level for all units, although with a lower level of significance for the Junior/Senior undergraduate Quiz 4 ($p = 0.005$).

Part of the variation in the number of participants within the high school and freshman education levels (Table 2) is due to student absences during pre-quiz or post-quiz lessons. Due to time limitations, one high school instructor was unable to continue testing the curriculum unit after completing the first challenge. One university professor chose to use Challenge 2 but not the other challenges in her junior/senior level imaging class, thus greatly increasing the number of students on that quiz alone.

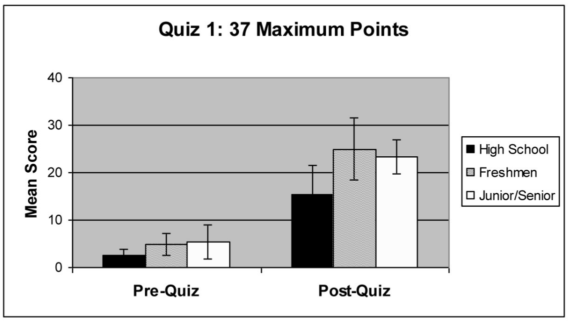

Fig. 1. Quiz 1 pre- and post-test scores for high school students, freshmen, and undergraduate juniors and seniors. The maximum possible score on this quiz was 37. Error bars indicate +/− one standard deviation.

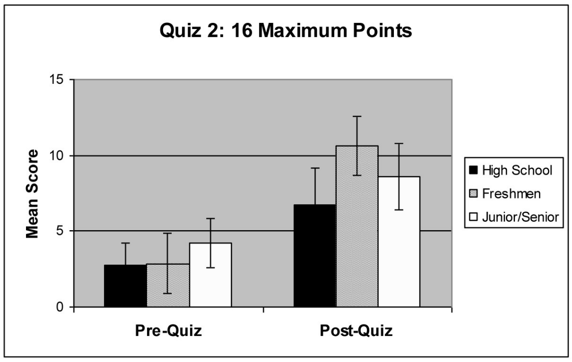

Fig. 2. Quiz 2 pre- and post-test scores for high school students, freshmen, and undergraduate juniors and seniors. The maximum possible score on this quiz was 16. Error bars indicate +/− one standard deviation.

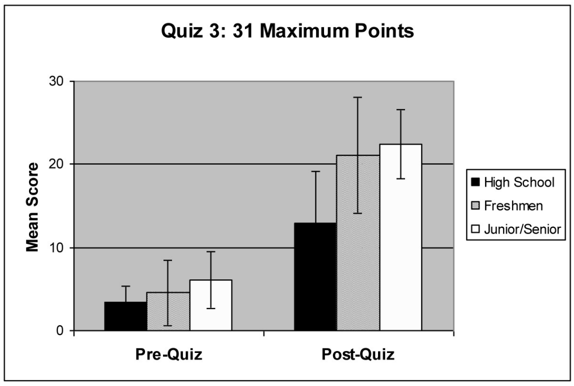

Fig. 3. Quiz 3 pre- and post-test scores for high school students, freshmen, and undergraduate juniors and seniors. The maximum possible score on this quiz was 31. Error bars indicate +/− one standard deviation.

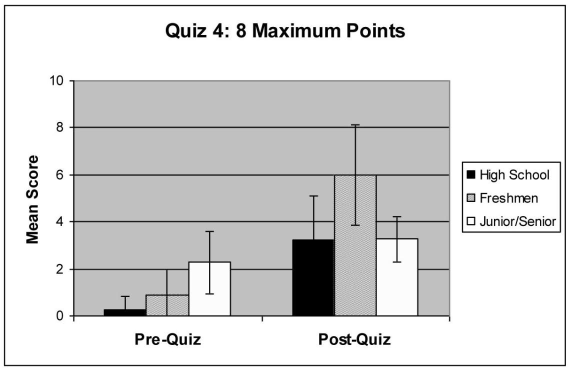

Fig. 4. Quiz 4 pre- and post-test scores for high school students, freshmen, and undergraduate juniors and seniors. The maximum possible score on this quiz was 8. Error bars indicate +/− one standard deviation.

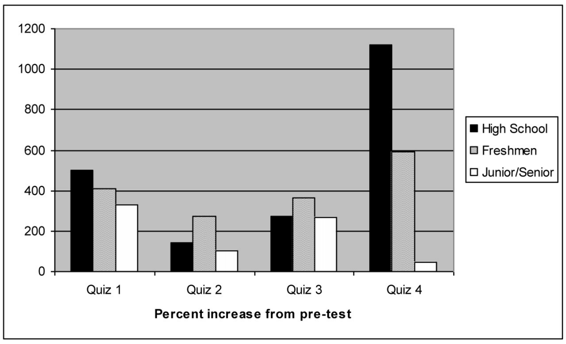

Fig. 5. Percent increase in score from pre-quiz to post-quiz, calculated as (Post Score—Pre Score)/Pre-Score.

On Quiz 1, high school students had difficulty completing and labeling drawings that illustrated coherent scattering, the photoelectric effect, and Compton scattering. The high school students were also not as thorough in explaining why ice has a different attenuation coefficient than water and which is higher of the two.

On Quiz 2, student performance was more varied, with fewer commonly missed items. Answers regarding the advantages of using an intensifying screen did not meet the level of thoroughness prescribed in the scoring rubric.

On Quiz 3, student performance was also more varied, with fewer commonly missed items. High school students were less thorough in their answers regarding the relationship among focal spot size, distance between the object and detector, and penumbra width. High school students also seemed to show less work, and score more poorly on our rubric that older students, on a question asking them to use data to calculate penumbra and the length of an object.

On Quiz 4, all students at all levels performed particularly poorly on a question that asks students to explain what will happen to the projections at different angles if a CT scanner takes x-ray projections of a sphere that is not centered on the scanner's axis of rotation. The students at all levels did very well on a question asking them to draw a plot of the signal intensity that would be created in a CT projection. Some variation of performance by level was seen: High school students had more difficulty explaining the difference between a CT image and an x-ray image, while undergraduate students had difficulty drawing a back projection based on signal intensity.

3.4 Surveys

While most of the categories did not show a significant difference in student opinions, the high school physics result for the questions related to their performance in physics class (seven questions on a Likert Scale of maximum 5) increased from 17.7 to 19.3 ($p < 0.05$; maximum total of 35) demonstrating that their opinion of their performance in physics increased after going through the unit. At the freshman level, the students increased their opinions of their ability to use mathematical and problem solving skills from 36.3 to 39.8 ($p = 0.01$; 14 questions for a maximum total of 84). Additionally, their Engineering Concept result increased from 11.4 to 12.5 ($p < 0.05$; maximum score of 36). This means their understanding of what an engineer is like and does is more favorable following the curriculum unit. No additional significant differences were found in the survey results.

4. DISCUSSION

Of the three education levels, the freshmen showed the greatest improvement across all four challenges. While that might be expected compared to the high school level, one reason freshman outperformed the junior/senior level could be that greater focus and time was devoted to the curriculum unit in that classroom, as compared to the junior/senior classes. Additionally, the different levels of selectivity of the two universities at the college level must be considered as well as potential instructor effects. At each of the education levels, students had a demonstrable increase in knowledge regarding x-ray and CT shown by their quiz results. All developed instructional materials were easily adapted into various learning environments, accomplishing the project goals across all levels.

Use of this curriculum unit at the junior/senior undergraduate level serves primarily to teach specific imaging concepts effectively to emergent engineers who may use such knowledge in their careers. At the high school and first year college level, the unit serves more general purposes. The benefits are that it provides context for learning key mathematical and physical concepts, exercises learners' ability to apply knowledge, and perhaps most importantly generates interest in applications of science, technology, engineering, and mathematics (STEM) at a time when learners often become disengaged with STEM disciplines. This disengagement can in part be attributed to boredom with drill-and-practice instruction, lack of apparent applications, and perceived difficulty of STEM material. The hands-on nature and inclusion of challenges that build on each other in this curriculum unit aim to counter disengagement. Additionally, the Legacy cycle has been shown to increase learners' ability to transfer their knowledge to new areas, instead of forming 'inert' knowledge that cannot be called upon when needed. Indeed, based on interest survey results, the curriculum unit did lead to high school students increasing their opinion of their own performance in physics, as well as freshman students improving their confidence in their ability to utilize mathematics and problem solving skills and developing more favorable opinions of what engineers are like and what they do. Engineers do many things other than just solving complex mathematical equations. They utilize strong social skills in many cases as they work with a variety of constituents, and they work on solving practical problems. These attitude changes may help increase the likelihood of young scholars choosing engineering professions. With the addition of more curriculum units implemented into these classrooms, further significant, positive changes in opinion may result. One reason for so many insignificant changes in the survey results could be the length of time spent on the unit. At the high school level and in one of the undergraduate classes, the imaging instructional materials were only used for a portion of the semester.

Though on average students did not fully master the concepts tested in the quizzes, it should be noted that the high demands of this study's rubrics for evaluating student performance artificially lower the reported achievement. Each answer according to the study rubric required full work to be shown at each step when often students were able to minimize the steps they took to arrive at a correct answer. Additionally, open ended questions had multiple aspects to a complete correct answer that often included small details most students either did not remember or think were necessary for their response. Although the challenging rubric would likely not be appropriate for use by an instructor as a standard for student mastery of the overall concepts of x-ray and CT, it was helpful in evaluating the effectiveness of the curriculum unit.

5. CONCLUSION

A curriculum unit based on the Legacy Cycle and safe, inexpensive hands-on learning used in classrooms at the high school, undergraduate freshman, and junior/senior levels was developed and shown to be effective in teaching concepts from x-ray imaging and computed tomography. Additionally, attitude survey results show a significant increase in high school student's opinion of their own performance in physics, and freshman student's opinions of their own math and science performance, as well as their understanding of what an engineer does.

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APPENDIX 1

Each of the statements on this survey expresses a feeling that a particular person has toward mathematics, science and engineering. There is no right or wrong answer to any question. You are to show, on a six-point scale, the amount of agreement between the feeling expressed in each statement and your own personal feeling. The six points are:

Very **S**trongly **A**gree **(VSA),**
Strongly **A**gree **(SA),**
Agree **(A),**
Disagree **(D),**
Strongly **D**isagree **(SD),**
Very **S**trongly **D**isagree **(VSD)**

Please rate how much you agree with these statements about yourself.

STATEMENT	**YOUR RATING**					
	Very strongly Agree					Very Strongly Disagree
I can use a lot of different mathematical methods to solve a particular problem.	VSA	SA	A	D	SD	VSD
Engineers spend most of their time doing complex mathematical calculations.	VSA	SA	A	D	SD	VSD
Engineering would be a highly interesting profession for me.	VSA	SA	A	D	SD	VSD
I do not attempt to work a problem without referring to the textbook or class notes.	VSA	SA	A	D	SD	VSD
My mind goes blank, and I am unable to think clearly when doing math.	VSA	SA	A	D	SD	VSD
Problem solving fascinates me.	VSA	SA	A	D	SD	VSD
Engineers deal primarily with theory.	VSA	SA	A	D	SD	VSD
A problem with engineering is that engineers seldom get to do anything practical.	VSA	SA	A	D	SD	VSD
I feel a sense of insecurity when doing math.	VSA	SA	A	D	SD	VSD

STATEMENT	YOUR RATING					
	Very strongly Agree					Very Strongly Disagree
I get flustered if I am confronted with a problem different from the problems worked in class.	VSA	SA	A	D	SD	VSD
I do not feel that I have a good working knowledge of the mathematics courses I have taken so far.	VSA	SA	A	D	SD	VSD
I have more confidence in my ability to deal with mathematics than in my ability to deal with other academic subjects.	VSA	SA	A	D	SD	VSD
Most engineers have poor social skills.	VSA	SA	A	D	SD	VSD
Engineers spend relatively little time dealing with other people.	VSA	SA	A	D	SD	VSD
I approach math with a feeling of hesitation, resulting from a fear of not being able to do math.	VSA	SA	A	D	SD	VSD
I feel a definite positive reaction to mathematics; it's enjoyable.	VSA	SA	A	D	SD	VSD
If I am confronted with a new mathematical situation, I can cope with it because I have a good background in mathematics.	VSA	SA	A	D	SD	VSD
Doing experiments in school make me think about how to answer my own questions.	VSA	SA	A	D	SD	VSD
I am good at thinking of interesting science questions to investigate.	VSA	SA	A	D	SD	VSD
I am confident in my abilities to use computers to research my ideas.	VSA	SA	A	D	SD	VSD
I am confident sharing my ideas with others through writing.	VSA	SA	A	D	SD	VSD
I am confident sharing my ideas with others by talking to the whole class compared to writing them down.	VSA	SA	A	D	SD	VSD
Good science and math skills are all you need to be a good engineer.	VSA	SA	A	D	SD	VSD
I am interested in becoming an engineer.	VSA	SA	A	D	SD	VSD
I am interested in working in a field that builds medical devices that help doctors figure out patients medical problems.	VSA	SA	A	D	SD	VSD
I am interested in designing devices people can use to make their life easier.	VSA	SA	A	D	SD	VSD
I know I would be a good engineer.	VSA	SA	A	D	SD	VSD
I am among the best in school	VSA	SA	A	D	SD	VSD
I have a good feeling about my achievement in school	VSA	SA	A	D	SD	VSD
I know the answer to questions faster than my classmates	VSA	SA	A	D	SD	VSD
I get high marks easily	VSA	SA	A	D	SD	VSD
My achievement is generally at least as good as that of my neighbor in class.	VSA	SA	A	D	SD	VSD
I think on my own.	VSA	SA	A	D	SD	VSD
Solving problems is easy for me	VSA	SA	A	D	SD	VSD
I am as clever as I would like to be	VSA	SA	A	D	SD	VSD

STATEMENT	YOUR RATING					
	Very strongly Agree					Very Strongly Disagree
I am content with my ability to speak in front of the class	VSA	SA	A	D	SD	VSD
Sometimes I feel superior to others and I believe they can learn from me.	VSA	SA	A	D	SD	VSD

For the following questions, please circle the code that best completes these statements as they relate to you.

	Very **G**ood	**G**ood	**A**verage	**F**air	**P**oor
I comprehend what is taught in physics	**VG**	**G**	**A**	**F**	**P**
I can remember what is taught in physics	**VG**	**G**	**A**	**F**	**P**
In my own judgment I think my performance in physics is . . .	**VG**	**G**	**A**	**F**	**P**
My participation in my physics class is . . .	**VG**	**G**	**A**	**F**	**P**
I believe that my classmates regard me as being____ in physics	**VG**	**G**	**A**	**F**	**P**
I believe that my teacher rates my achievement in physics as being . . .	**VG**	**G**	**A**	**F**	**P**
I expect that my achievement in physics will be. . . .	**VG**	**G**	**A**	**F**	**P**

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