Expanded version of an invited paper to be published in the Proceedings of the International Conference on Physics Education: Toward Development of Physics for All, Tokyo, 2006

Transfer of Students' Learning: Physics to Medical Imaging

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ABSTRACT

Many of the diagnostic devices which are used by physicians have their technological foundation in contemporary physics. To understand techniques such as magnetic resonance imaging (MRI) and positron emission tomography (PET), students require knowledge of nuclear and quantum physics and must also transfer learning that they have learned in classical physics or every day life to these medical applications. Our present research investigates this transfer of learning and its application to understanding both the medical techniques and some classical analogs. We are finding that students can sometimes use analogies and transfer their learning very well. However, some transfer of learning is inappropriate but very robust. The project's Web site is http://web.phys.ksu.edu/mmmm/.

1. INTRODUCTION

The work that I will describe here is an extension of the Visual Quantum Mechanics project which developed interactive teaching materials for secondary and early university students. This visualizations and hands-on activities showed that one can teach qualitative aspects of quantum physics to students who have limited mathematics or physics background. [1-3]

In our present efforts we are creating instructional which help students learn how contemporary physics in used in modern medical diagnosis and treatment. So far we have concentrated mostly on medical imaging. The audience for this material is university students who wish to become physicians. In the United States before students can enter medical studies they usually complete a four-year bachelor's degree. Included in that curriculum is an algebra-based physics course. This physics course is one year in duration and is the only physics course that these students will complete. The university course is required by most medical colleges before the students can enter formal medical studies. (Some but not all will have completed a physics course in secondary school. For most students a secondary school physics course cannot substitute for the university course.)

Our effort, called Modern Miracle Medical Machines, seeks to introduce contemporary physics that is relevant to the students' interests. We hope to accomplish this goal by creating a series of learning units that can be integrated into the existing course. We are doing so in a two step process. First, we conduct research to understand how students reason when they are asked to apply physics to contemporary medicine. This research includes presenting students with some of our teaching ideas to see how they can transfer their previous learning to a new situation. The second step is to develop active-engagement materials that can be used in physics courses for future medical students.

Until now we have focused primarily on the research. Thus, this paper will concentrate on the part of the research that we have conducted.

2. OVERVIEW OF INSTRUCTIONAL MATERIALS

Our approach is to focus on the physics and not the medicine. We cannot teach students how to analyze medical images but we hope to help them understand what the physics is underlying the creation of those images. We also want to focus on qualitative problem solving so that students are not just plugging numbers into equations it. We are following the same teaching-learning concepts that Professor Redish discussed in his plenary lecture at this conference. We want students to be able to reason rather thoroughly. Thus, throughout the whole process we plan to use both visualizations and analogies to help the students understand the rather abstract and complicated ideas of modern medical imaging.

We plan to focus on five topics – X-rays and CT Scans, Positron Emission Tomography, Ultrasonic Imaging, Magnetic Resonance Imaging, and Lasers in diagnosis and surgery. So far most of our work as been related x-rays and CT-scans and to positron emission tomography: In this paper I will discuss our research related to student understanding of positron emission tomography

3. RESEARCH METHODS

Our research has two basic steps. First, we conduct one-on-one interviews with students. We ask some questions of those students and try to understand how the students are reasoning about the application of physics to modern medicine and what type of mental images or mental models they have concerning that application. Second, we complete a type of interview that is frequently called a teaching interview. We base this step on the results of individual interviews. Here we work with either individual students or small groups of students, but we follow a teaching protocol. We try to teach the students something new and at the same time try to understand how they are reasoning as they are learning the new concepts. Thus, in the first part we learn about what the students know and how they apply the knowledge that they already have. In the second – the teaching interview – we try to understand what they can learn if we give them some additional information. [4-6]

In our efforts we have been guided by research on how learning occurs. One useful concept is Vigotsky's zone of proximal development. A short and incomplete summary of this idea is that students in small intellectual steps for which they have been prepared. If intellectual step are too big well, the students cannot make them. Thus, we are trying to understand what those small steps are and which small pieces of information we can provide students in order to help them learn and build new mental models. [7]

We are also using various ideas about transfer of learning. Redish mentioned that students tend to bring in pieces of knowledge and apply those pieces to new information. Sometimes they apply it appropriately and that helps them move forward. Sometimes they don't apply it appropriately and can get moving off in a wrong direction. [8, 9]

4. POSITRON EMMISSION TOMOGRPAHY (PET)

The picture in Figure 1shows a positron emission tomograph of a person with cancer this imaging process involves injecting a positron emitter into a human body. The chemical element that has the positron emitter as part of it will be taken up by some part of the body that uses this chemical. For example, in brain imaging fluorine-19 is very useful because it is used in certain types of brain activities. The isotopes are short half-life nuclei that that emit positrons. Of course, inside the body are many electrons, annihilation occurs quickly. The annihilation process usually results in two gamma rays. Those gamma rays come out of the body. From their detection computers can work backwards to determine where the annihilations occurred and create pictures such as Figure 1.

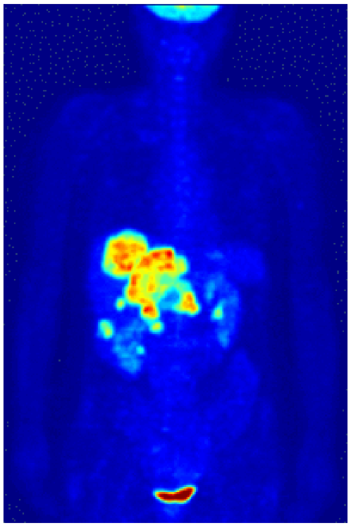


Figure 1: A sample image suing positron emission tomography (From Wikimedia Commons)

Because the locations of the positron emitters depend on chemical reactions that are occurring in the body at the time of the imaging, this tomography is fundamentally different from normal magnetic resonance imaging (MRI) or CT scans. With both MRI and CT the image tells the physician where objects are located and what has already happened in the body. With PET the physician sees what is happening at the time of the imaging and is, thus, looking at body functions.

When it was first developed, PET was primarily a research technique to look at brain function and see what parts of the brain were active when people were thinking about different things. Now it is increasingly being used as part of diagnosis.

The physics involved is ranges from basic mechanics to radioactivity. (See Table 1.)

Table 1: The major physics concepts involved in positron emission tomography

Random vs. real coincidence	Image Processing
Distance, velocity, time	Photoelectric effect (for detection)
Radioactivity	Matter – antimatter annihilation
Photon scattering	

5. ANALOG ACTIVITIES

One component of image construction involves using the speed of light, measuring the time difference between the detection of the two gamma rays, and determining the distance from the detector to where they were located. Another is related to determining a lines through the body upon which the event producing the gamma rays must have occurred (called the line of response or LOR).

For the present our research focuses on these two concepts. We have created some analog activities that we are using in the teaching interviews. For the moment I'll just call them the cart activity which involves two collision carts and the light activity which involves a series of small light emitting diodes (LEDs).

The cart activity concentrates on the concept of coincident events. For gamma rays and a set of detectors we detect two gamma rays which arrive at their respective detector a fraction apart. The difference in the time between those two detections can be used to determine the location of the event that created both gamma rays. To help students understand this concept we set up an experiment. We use two collision carts with magnets in them. When the carts are released, the magnets repel and the carts move away from each other. A student in front of a large board -- a location where he/she cannot see the location of carts where they are released (Figure 2). Another student is on the other side of this board and releases the carts. The first student can see is when the cart beyond the two ends of the board. We ask him/her to determine the approximate location of the release by measuring the time difference between the two carts striking the end of the track. For example, if the cart on the left strikes the end much sooner than the one of the right, students would conclude that the release (event) occur on the left side of the center of the board.. If they see that both carts strike at about the same time, they would assume that event occurred approximately in the middle.

Figure 2: A view of the cart activity as seen by the second student. The first student sits on the far side of the vertical board.

In the light activity we have used the cylinder shown in Figure 3. (We bought it in a cooking store. Generally it is something in which one stores cakes.) Inside it is an array of light emitting diodes. They evenly spaced on the inside circumference of the cylinder and are all identical in size and brightness. When a switch is activated, two of the light emitting diodes come on. This activity is another analog for the two gamma photons.

Figure 3: The apparatus used for the light activity

Unlike the cart activity, we are working now in two dimensions and with several different events. Each event has two LEDs on to represent the two gamma photons. By recording the location of several events and establishing the line of response for each of them, the students are to work backwards and try to determine where inside this cylinder the events which produced the light would be.

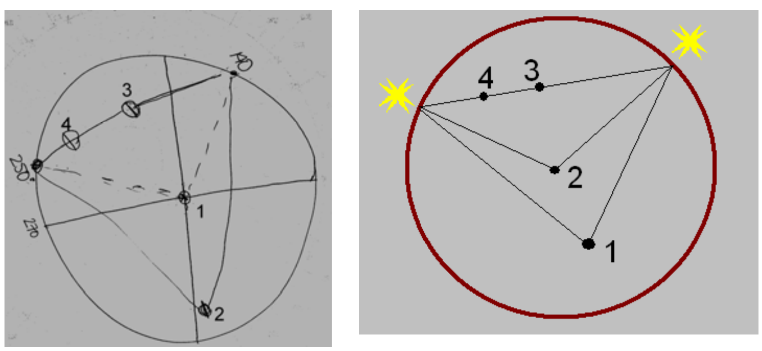
6. PRELIMINARY RESEARCH RESULTS

Our research is investigating how students understand each of these analogies, how they apply the physics that they already know, and how they use the analogies to understand medical imaging. One of the most interesting results is that students frequently apply symmetry to these situations even when symmetry is not relevant. For example, if we start with the light activity we find that the students will decide that the event related to the light must have occurred from the center of the circle. They use reasoning that light appears at the edge of the cylinder so this event must have happened at the center. Fourteen out of 16 students who completed this activity used this type of reasoning.

A typical student response is "….I am so used to think that if you are gonna have two points at the end on the circle then obviously their start point is the center…" That response is in typical Mid-West American English. A reasonable translation to standard English is, "If two lights appear on the circumference of a circle, then obviously the event is at the center." This conclusion is very general among the students.

In the teaching interviews we try to influence the students to change their idea by asking questions such as, “Based on what you have seen, is it necessary for the event to have occurred in the middle?” Frequently, the students will then decide that the event could have occurred elsewhere – almost any random point inside the circle. Then we will remind them that photons have momentum and random locations do not conserve momentum. This fact leads students to decide that the event must have occurred on a straight line between the two lights. However, most of decide the event must have been in the center of that circle. For example, “…kinda guess where the center is …I said the light source is at the center…I think the light source is.” (Translation: “I guessed that the light source is at the middle of the line.”) While the student says that he is guessing, he is applying symmetry. If the events occurred on a straight line connecting the two lights, it must have happened in the middle of that line. Then we will remind them of the cart activity where things could happen on a straight line but not necessarily in the middle. Finally, they will bring up the idea that it could have happened anywhere along that line.

This reasoning is illustrated in Figure 4. Part A is a student drawing with the numbers indicating the order in which she stated the location of the event. Part B has the same concept but is a representation with a clearer and neater drawing.. As we have described that student started with the center of the circle, then moved to point #2 (somewhat random location), then up to point #3 (middle of the line of response) and finally to point #4 (any location along the line of response). The changes were a result of questions asked during the teaching interview.



(a) (b)

Figure 4: Part a (left) shows the students drawing while part b indicate the result and the location of the lines. The numbers show the order in which the student selected the locations of the event.

We frequently see various pieces of knowledge being applied during the students’ reasoning process. For example, for a light “closer is brighter.” The students will decide that one light is brighter than another. Once they decided that the event can be anywhere along the line of response, they will conclude that the event must be closer to the brighter LED. This piece of knowledge works in many situations with light. If two lamps are identical, the closer one will be brighter than the one further away. In our teaching interview 11 students concluded that the event must be in the middle of line of response. Seven of them used this type of reasoning to decide that the event must have occurred in the middle of the line of response. For example, “I would have to look at the light again ….if the intensity of the light is same at both the sides…which I believe it is … I believe that the…it have to have happened at the middle.” That is, the two lights are the same brightness, so the event must have occurred in equidistant from both of them. This reasoning is good for some situation, but not appropriate here.

In a similar way 2 of the 11 students applied the idea that closer is bigger. For example, “the diameter of the light was the same so I think it should be equidistance from the light source.” Again this reasoning leads to the event being in the middle of the line of response.

The final two students who concluded that the event must be in the center of the line of response used a reasoning based on timing. For example, “You have to see when the lights turned on … I thought they turned on at the exact same time.” Figure 5 summarizes the number of students who used each type of reasoning.

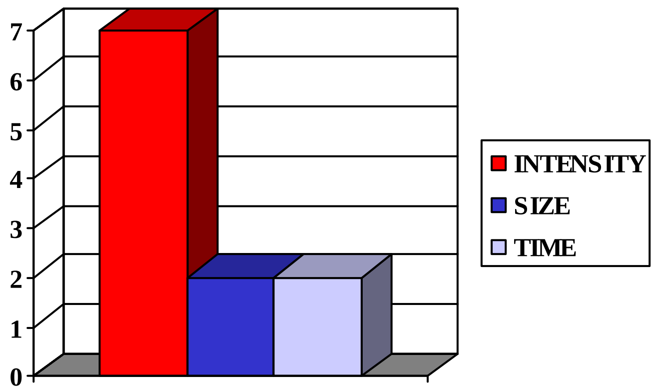


Figure 5: The number of students who used each of three different types of reasoning. All of these students completed the light activity first.

In all of these reasoning patterns we see students using knowledge that they have acquired either from other formal courses or from every day life. However, the reasoning is not appropriate to the situation. However, by using some carefully constructed questions we are able to help them see why the ideas which they have applied are not correct for this situation. They can then be led to transfer of more appropriate learning and to a correct conclusion.

The students that we have just described completed the light activity before they work with the cart activity. We have also investigated the order of the activities to see if doing the light activity first might result in a different transfer of learning. We have tentatively found that the student transfer knowledge differently depending on the order. As shown in Figure 6 all students who complete the cart activity first (CL) focus on the time of events as being the critical variable while the one who completed the light activity first are distributed as discussed above. So order in which students complete activities seems to strongly influence what learning they transfer to a new situation. At this time we do not fully understand why this difference occurs, so we will be conducting further research.

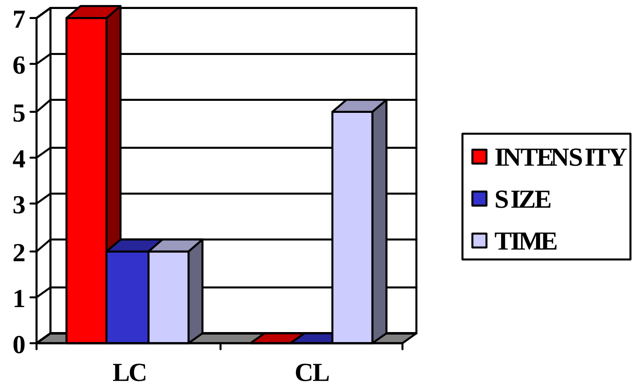


Figure 6: Comparison of the types of learning transferred for students who completed the light activity first (LC) and those who completed the cart activity first (CL).

7. CONCLUSIONS

The students tend to draw on both their knowledge of physics -- their learning of past physics as well as their everyday experiences -- in building their own model of how these ideas are important in positron emission tomography. The hands-on activities can be very influential if we do them in the right order. If we do them in a different order the students tend to go off in a direction that is not productive

By providing carefully selected questions we can encourage students to use their previous knowledge in appropriate ways and build their own models related to medical imaging. Because most of the physics that they need has been learned in other contexts, this method of facilitating transfer is an important component of helping the students to learn efficiently and to encouraging them to construct their own knowledge in new contexts.

We are now using this research as well as some on x-rays and CT scans to build lessons on the application of physics to medical imaging. We hope to have first versions of the lessons available by late fall and certainly not later than the end of the year.

8: ACKNOWLEDGEMENTS

Our collaborators in the Modern Miracle Medical Machines project include"

- Sanjay Rebello and Dyan Jones, Kansas State University, USA,
- Hartmut Wiesner and Giuseppe Colicchia, Ludwig-Maximilians University, Munich, Germany,
- Manfred Euler, Institute for Science Education, Kiel, Germany, and
- Leroy Salary, Norfolk State University, USA

This work is supported by U.S. National Science Foundation under Grant 04-2675. . The web site for this project is http://web.phys.ksu.edu/mmmm

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