# MODERN MIRACLE MEDICAL MACHINES: PHYSICS INSTRUCTION FOR FUTURE MEDICAL STUDENTS

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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. Thus, these instruments can provide motivation to study contemporary physics. To exploit this motivation we have built on the Visual Quantum Mechanics project (http://web.phys.ksu.edu/vqm/) and are developing learning units that focus on applications related to medical diagnosis. Units are planned on x-ray production and absorption, MRI, PET, CT scans and LASIK surgery. Initial efforts have focused on understanding students' models of these procedures before instruction, gathering useful Web-based resources for teachers and developing instructional materials on PET and LASIK procedures. The project's Web site is http://web.phys.ksu.edu/mmmm/.

## 1 Introduction

This project builds on Visual Quantum Mechanics,[1] which has been a long term effort to teach quantum physics with visualization and simple experiments. The quantum mechanics materials are aimed primarily at high school students or beginning college students. They are an attempt to avoid the mathematics of quantum mechanics while enabling the students to understand some of the concepts through the processes of visualization and simple experiment. It provides a foundation on which we are building the medical machines project which is the subject of this paper.

The method of educating future physicians in the US is somewhat different from that in many other parts of the world. Most students who wish to be physicians will complete a full four year university education before starting their formal medical study. Our project addresses these students. Frequently these students will complete a bachelor's degree in a biological science. During that time they will take one year of algebra-based physics. That course will be the only physics course they will complete in their entire university and medical school studies.

We would like to change parts of this course. Realistically a complete change in the course is not likely. So we are trying to bring some modern physics in the context of medical applications into this course. However, we wish to include this content throughout the course—not just at the end when modern physics is typically presented.

## 2 Physics Education Research Foundations

To create successful instructional materials we need to base our development on research in physics teaching and learning. Much of the research that has been done will be useful, but we will need to do some more as well. Thus, we are now conducting some research on students' reasoning and mental models related to some topics in modern physics.

Much of the research on student mental models will be in the format of traditional interviews. In discussing x-rays a student will be given a series of images and asked to describe them. These images will be rather obvious x-ray images except that one is a sonogram. The students will be asked a series of questions about these images, including what they know about how they are made, what physics is involved in them and so forth.

For some topics, particularly positron emission tomography, we cannot expect the students to know much at all. So we plan to follow a protocol that is sometimes called a teaching interview. We teach the topic to a few students. As we are teaching them, we are listening to them interact with each other and interact with us. In the process we learn how the students are thinking about the concepts and the models.

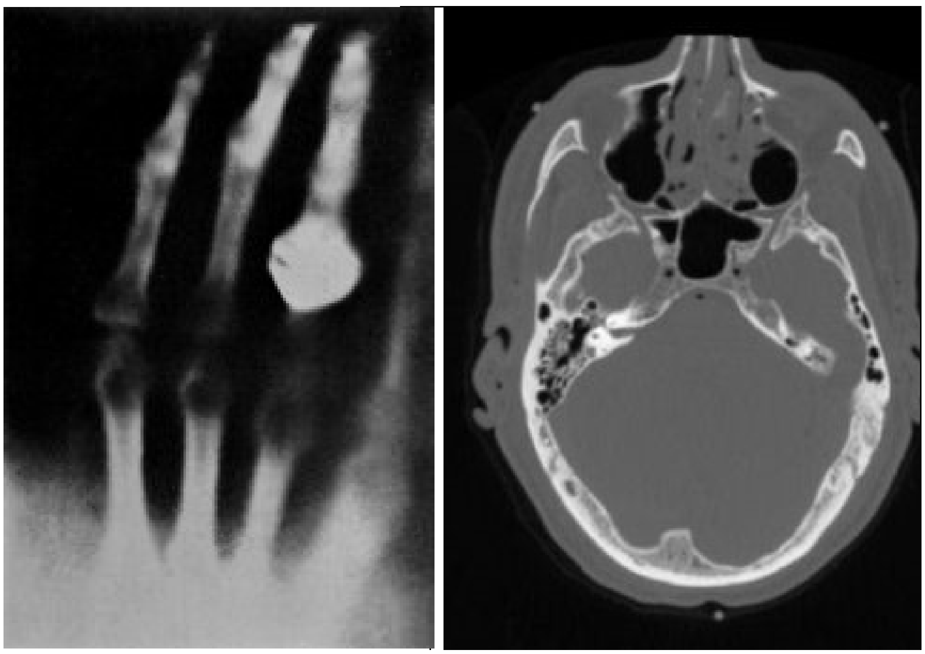
Using that research and the research of others we will develop some active learning materials and then integrate that into the physics course for the medical students. We hope to accomplish this development in such a way that a professor could decide to take one or two weeks at various times during the semester and replace whatever he or she has done in the past with this type of material.

## 3 General Approach to the Science

Our approach to the science involved is to focus on the physics and not the medicine. We would not expect a student who has completed our lessons to be able to interpret an image from positron emission tomography. However, that student should be able to explain something about how that image was made and what physics principles were involved. These materials will focus on qualitative rather than quantitative problem solving. To do so the materials will incorporate visualization very frequently.

In Figure 1 you will see an example of some visualizations. On the left side of the figure you see an x-ray of Frau Roentgen's hand which was the first x-ray ever published. A contemporary application of this same idea is computerized tomography. This image is created by a series of x-rays passing through an object. The device rotates the x-ray beam all the way around the object. Then a computer adds these results to obtain a picture of the inside of a patient. In the image in Figure 1(b) we see the head of a male cadaver.

In some ways x-rays probably should not be considered modern physics. They were discovered over 100 years ago. However, using them as part of computer tomography scans is relatively new. So, we will include them in our lessons.



(a) (b)

Figure 1(a). The first x-ray. The hand of Wilhelm Roentgen's wife with a ring on her finger. (b) A CT scan from the Visible Human Project of the US National Library of Medicine. (http://www.nlm.nih.gov/research/visible/visible_gallery.html)

Another imaging technique is positron emission tomography. In this method one introduces a positron emitting source into the body. Those atoms are taken up by certain parts of the body because of the chemical properties and then positrons are emitted. They annihilate with electrons. The resulting two gamma rays exit from the body. By doing coincidence experiments one can learn about what is happening inside different parts of the body. In fact, positron emission tomography has been used to watch people think. For example, in one research effort different kinds of music were played. The researchers used this type of imaging to see how the brain changes while listening to various types of music.

Magnetic resonance imaging (MRI) is another rather common imaging technique as are various applications of lasers which are used in both diagnostics and surgery. In this paper we cannot cover all of them. So we will focus on x-rays, including CT scans and positron emission tomography.

## 4 Development Methodology

Our methodology for creating the materials is the procedure described by Wiggins and McTighe. This approach is sometimes called a backward design because one starts with the goals that you want to accomplish and work backwards to design the teaching materials. So, first we identify the goals. Then, we try to determine how we will know when the students have met our goals. Finally we design and create the learning materials. At the same time everything that we do will be based on ours and other peoples' research on how students learn.

## 5 Medical and Physics Topics

Table 1 lists the topics on which we are working now. We are preparing teaching-learning materials so that these topics can be studied at various times during a one-year course. They do not have to be taught after the student has studied all of the physics. For example, time of flight and coincidence are two of the very important concepts that are involved in positron emission tomography. All one needs to know to understand time of flight is distance, time and velocity. Likewise, x-ray production is basically a conservation of energy problem. Some energy comes in; it comes out in a different form.

Table 1. Topics now being considered for development.

| **Topic of Proposed Learning Units** | **Physics Prerequisite** |
|---|---|
| Time of Flight, Coincidence & PET | Distance, time and velocity |
| Light & X-Ray Production | Conservation of energy |
| X-Ray Detection 1: Film & Fluoroscopy | Conservation of energy |
| X-Ray Detection 2: Image Intensification | Conservation of energy & photoelectric effect |
| X-Ray Detection 3: Charge Couple Devices | Circuits and semiconductors |
| Computer Tomography | Basic ray optics |
| Ultrasonic Imaging 1: Reflection & Transmission | Sound propagation & reflection |
| Diagnosis of Eye Defects | Ray & physical optics |
| Refractive Eye Surgery with Lasers | Basic optics of lenses |
| Dermatology | Absorption and reflection of colors |
| Magnetic Resonance Imaging (Classical version) | Angular momentum and resonance |
| Magnetic Resonance Imaging (Quantum version) | Energy levels in atoms |

To be able to discuss a variety of detection issues we will need to explain the photoelectric effect rather early. We think we can teach it from the point of view of conservation of energy and some interactions of light with matter. As an aside, probably the biggest improvement in medical x-ray use since Roentgen is improvement in detection. One hates to even think about how many x-rays — what dosage Roentgen's wife absorbed — when the image of her hand was created. Today physicians strive to maximize the information while minimizing the amount of dosage of x-rays.

## 6 An Example: Positron Emission Tomography

Positron emission tomography is frequently used to make images of the brain. A positron emitter is injected into the body. These atoms go to some location in the brain based on chemistry. The positrons then annihilate with electrons and two gamma rays – each with energy of 0.511 MeV – are produced. To determine the location of the annihilation within the brain, the travel time from the location to the detector is critical. In PET the patient is surrounded by detectors. When a coincidence between detection of two gamma rays within a certain amount of time occurs, the computer can work backwards and determine the location of the source of the annihilation. Then the computer creates a "map" of annihilation locations.

We will teach time of flight and coincidence rather early in the physics course. The lesson requires just two carts on an air track or two collision carts. One student hides the carts behind a board and releases the carts. Once they emerge from behind the board, another student, who can only see the ends of the track, measures the time difference between the two carts hitting the ends. With this information and the measured velocity of the carts, the students can work backwards and determine the location of the release point. Thus, the students have learned the basic idea of determining where the annihilations occur in PET. And they can do so by applying just some simple classical physics.

For a more complete understanding of PET students need some additional physics. For the detection of gamma rays they must understand the photoelectric effect. Radioactivity is involved as well as matter, antimatter and annihilation. We will not introduce all of these concepts at once. Instead, we will have the students complete several small lessons that occur throughout the semester. With each one we will build upon it and the previous lessons. Then once we have all the pieces, we will help the students put it together in a summary which describes all of the components of PET.

## 7 Learning About Image Formation with Computer Tomography

Computer tomography has been a major way of looking inside the body now for over 20 years. So, we will teach, through interactive lessons, how the computer uses a large collection of data to create an image of the inside of a human. One method of teaching will use analogies. A simple method is to give the students a device with hidden objects inside. They are asked to use a laser pointer to determine the location of the objects. In the simplest experiment the objects are opaque. When the student scans across the device and no light comes through, the student has located the object. At the next level of complexity the opaque objects are replaced by several small vials of water with different shades of food coloring in each one. Now, the students see some absorption but not total absorption. It is possible from that to try to map out where the green water is, where the blue water is, where the red water is and so forth. We have been only partially successful with this experiment. One of the issues is that even a small laser is too intense for most of the inexpensive photodetectors. Thus, the absorption is not easily detected because enough of the beam is transmitted to give a maximum signal. We are continuing to work on this issue.

With help from Prof. Wiesner's group at Ludwig-Maximilians University in Munich we have been able to extend this analogy to computer tomography by adding a computer visualization. Figure 2 shows some pictures from this visualization. Students are able to create an object inside the "body" by placing dots at various locations. Then, they move their "x-ray source" around and see what kind of images they obtain. Or, they can work another way by starting out with some images and determining where the dots must be. With these types of simple experiments and visualizations we should be able to teach some of the basics of computer tomography without using Fourier analysis.

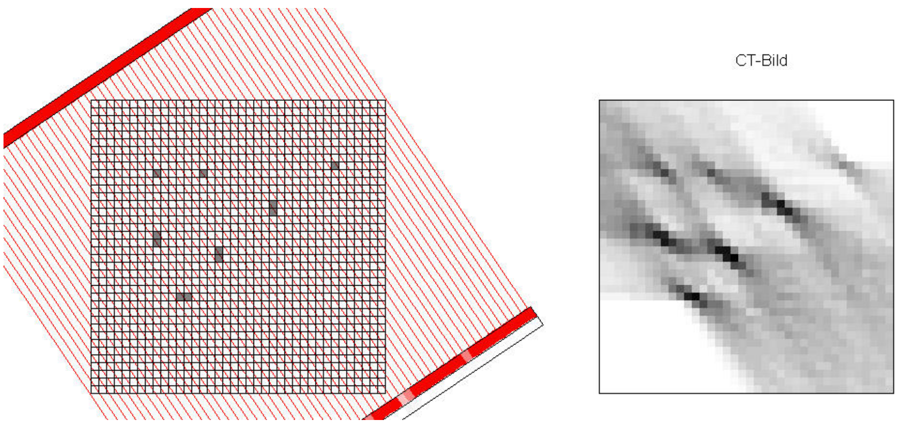


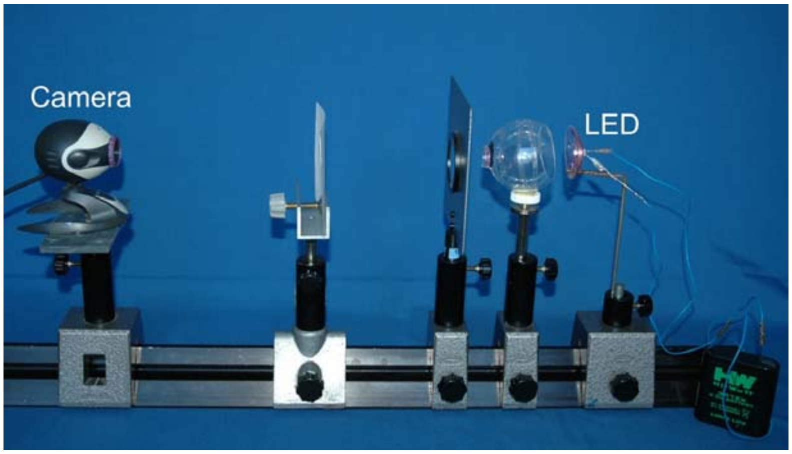

Figure 2. A visualization of the process involved with computerized tomography. The left side is a set of objects inside a "body." The lines represent beams with pass through body and are detected on the opposite side. The right side shows the image that would be created by a partial rotation of the source-detector apparatus. (Created with a computer visualization from http://www.physik.uni-muenchen.de/didaktik/.)

## 8 Lasers and the Eye

Another lesson in collaboration with the group in Munich is the diagnostic of eye defects. When we have our eyes tested, most of us still read letters off the charts on the wall, but scanning the eye for defects with a very low power laser is possible. The basic process is to send light into the eye. This light reflects off the retina, comes back out through the eye's lens and is detected. The shape of the detected light patterns enables a computer to map the defects with the eye lens and with the shape of the eye.

A simple optics setup with a model of the human eye can help students learn about this technique. However, one of the concerns is that students may think that they can point a laser at their own eyes. Even though we tell them they should never do this, the experiment may lead them to some hazardous behavior. So, a slight change in the experiment is to put an LED in place of the retina. (Figure 3)[2] Then, students can get the idea that by having light come through these various parts of the eye, one can map some of the defects. However, they do not see any lasers being pointed at the model of the eye.

We are also getting started on a LASIK surgery unit. LASIK surgeons use diagnostic techniques such as the ones described above. Then they use lasers to reshape the eye's lens. This process involves some basic optics as well as rather sophisticated




lasers.

Figure 3. An experimental setup so that the students can investigate using scans of the eye to determine the eye's defect. This version includes a Webcam so that the result can be shown to a large class. (See reference 2.)

## 9 Present Status

All of our materials are in some phase of early development. The work on x-rays involves a study of students' models of the process by which medical x-rays are created. Simultaneously, we have worked with the *Physik im Kontext* group at the Institute for Science Education (IPN) in Kiel, Germany to prepare some links to reference materials for teachers and students. Some of the interviewing with students is going on right now. For positron emission tomography we have some draft materials and will soon be preparing teaching interviews. LASIK surgery is at about the same level as PET. Image processing is a little less developed by us but the materials completed in Munich show great promise. The eye diagnosis concepts were a focus of some work this summer. At present we have translated and slightly modified the German versions.

## 10 Conclusions

Medical applications of modern physics provide a very good context for learning some basic physics. For future physicians the context has some intrinsic interest. We have not yet tested whether it can be learned at a qualitative level, but our experience over the last 10 years with teaching quantum mechanics indicates that we can create teaching materials with good learning results. The idea of including the materials throughout the course seems to work fairly well, at least in principle. Of course the challenge always is not to teach just so the students say, “Oh that’s interesting,” or that they memorize something, but so that they actually learn. Then, they can learn new models and apply the conclusions to other situations as well.

Our progress on this will be on our website, http://web.phys.ksu.edu/mmmm. Materials will be posted as we have them ready. We are interested in teachers who want to try the materials or would like to add to our research base if they can.

**Acknowledgments**

This project is being supported by the U.S. National Science Foundation under Grant 04-2675. Additional support came from the German Bundesministerium für Bildung und Forschung as part of the Physik im Kontext project. I also gained from the hospitality of the Didactics of Physics Group at the Ludwig-Maximilians University in Munich.

Collaborators include Spartak Kalita and Bijaya Aryal who are graduate students in physics education at Kansas State University, Leroy Salary at Norfolk State University, Hartmut Wiesner and Giuseppe Colicchia at Ludwig-Maximilians University, Munich, Germany and Manfred Euler at the Institute for Science Education (IPN), Kiel, Germany

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