MODERN MIRACLE MEDICAL MACHINES

Research-Based Curriculum Enhancements for the Pre-Med Physics Course

Contemporary medical procedures – diagnostic and treatment – involve sophisticated applications of fundamental principles of physics. By the time that students reach their "pre-med" physics course, they have heard of many such procedures and frequently know someone (or some pet) who has been subjected to these procedures. Yet, the physics course and textbook will, at most, mention them in passing.

Admittedly, many of these topics do appear in the table of contents of many algebra-based physics textbooks. However, they are generally 1-2 page textual presentations and not active engagement learning experiences. These textbook sections seem to be placed in the book to appease faculty who ask for relevance. However, the lack of importance to the central development of the physics is emphasized by frequently marking these sections as "Optional" and providing no homework problems related to them.[1]

The lack of instruction about physics applications to medical procedures is lamentable because:

- Showing the connections between medical applications and contemporary physics can make physics more appealing and interesting to a diverse student population such as that enrolled in the pre-med physics course. Many of these students think that physics lacks relevance. These students are frequently members of groups who are underrepresented in the scientific community.
- Contemporary physics is an exciting rapidly changing field. Yet, students in introductory courses seldom see it except at a very superficial level. If these students have quality learning experiences with these topics, they can better understand physics as it is done today and the scientific process.

To change this situation the physics teaching community needs instructional materials that are carefully constructed to help students build the connections between physics that they have learned and contemporary medicine. These materials must be based on research in student learning as well as research and development in medical procedures and physics. They must engage the students in an active learning process, yet do so in a way that enables an instructor to insert the materials without making a complete change in the way he or she teaches.

To address these concerns the *Modern Medical Miracle Machines* project will

- conduct research on the reasoning and models that students use as they transfer basic physics knowledge in the application of physics to contemporary medicine,
- develop active engagement teaching-learning materials to help students learn about the applications of 20th and 21st Century physics to contemporary medical diagnosis and procedures, and
- work toward a change in the culture of teaching introductory physics so that contemporary physics and contemporary medical applications are integrated throughout the algebra-based physics course, rather than being placed in secondary (optional) roles or at the end where it is never discussed thoroughly.

In reaching these goals we will build on the large quantity of research about how students learn and reason about physics, some of which has been completed by our physics education group at Kansas State. We will use this previous research that has been conducted during this project as a foundation to create interactive lessons. The instructional materials will include a broad range of techniques including hands-on experiments, interactive multimedia and traditional paper-and-pencil activities. Through the materials we will emphasize scientific model building and the connection between the macroscopic world of medical procedures and the nanoscale world of atoms and molecules.

These materials will be developed in close collaboration with the *Humanized Physics*[2] project that is developing similar materials on the applications of classical physics to understanding the human body and a similar project under development at the Ludwig Maximilian University in Munich.[3] We will also rely on our own work with *Visual Quantum Mechanics,*[4] a related effort which created visualizations for the modern physics course for majors and one previous experience of teaching a course on this topic to a small number of students. Thus, the instructional materials will build on research on learning and existing efforts[5] to create specialized physics learning materials for the pre-med audience.

CONNECTIONS TO NSF GOALS

This project will foster the integration of research and education by both conducting fundamental research on student learning and by creating resources to bring the pre-med physics students information about the applications of today's research in physics to medicine. Thus, we will be using current research and development in education, medicine and physics throughout our efforts.

The products of our research and development will be structured to reach the broadest possible spectrum of students. Showing how contemporary physics is related to human endeavors such as medicine, by itself, will appeal to a broader audience than the traditional physics course does. By testing our materials at universities that have large enrollments of African-American and Hispanic students, we will assure that the instructional materials appeal to students who are underrepresented in the sciences.

RESEARCH ON TRANSFER & APPLICATION OF KNOWLEDGE

Perspectives of knowledge transfer appear to share at least three common themes. 1) They look at transfer from the students' perspective rather than a pre-defined researcher's perspective, i.e. they ask what similarities the student sees in given situations. 2) They describe transfer as a dynamic phenomenon – one in which the learner dynamically constructs knowledge in the target scenario, rather than merely applying what they have learned previously. 3) They go beyond looking at transfer from a purely cognitive perspective and include socio-cultural factors in their discussion.

Part of our previous and current efforts involves research on students' mental models and transfer of learning from one domain to another. Our research demonstrates that student knowledge changes dynamically even during a clinical interview. Therefore, we focus on the dynamic *in situ* transfer and construction of knowledge by students and not solely on the answer.[6-13]

The goal of the research component of our project is to enhance the existing research base that sheds light on how students whose primary interest is in a scientifically related discipline (medicine) transfer their knowledge of physics to other topics. We will investigate students' abilities to begin with knowledge learned in their physics class, build mental models and use those models to understand better the underlying principles of tools such as lasers used in surgery and positron emission tomography. The principal hypothesis of this component of our work is that these students can build robust and coherent models and representations that help them understand physical phenomena and their applications.

We will begin by identifying the relevant concepts which students need and contexts in which they will need to apply these concepts. Some of these concepts will be studied as part of the traditional courses. For example, time of flight will be included in a normal study of distance, speed and time, but the context of positron emission tomography is not likely to be mentioned. Other topics may be mentioned but will need significant enhancement as part of the modules (e.g. x-ray production). In all cases, we will identify the concepts and the medical applications, then follow the research plan described below to better understand student reasoning and ability to transfer.

Phase I: Clinical Semi-structured Interviews: Semi-structured clinical interviews modeled after Piaget[14] provide a definite structure but allow for follow-up questions based on student responses. By including demonstrations and visualizations, students will be asked to predict the outcome of an experiment (real or virtual) and then they will observe it and compare their predictions with observations. Clinical interviews also involve "what if" and "how does it work" types of questions or thought experiments. The interview results will be analyzed as described below.

Phase II: Teaching Interviews: Teaching interviews[15,16] have a semi-structured format that involve up to three students at a time and may consist of up to three hour-long teaching episodes with an optimal hiatus of a few days in between successive episodes.[12] The teaching experiment enables us to probe more deeply into transfer in individual students as well as look at the social interactions component of transfer. Based on our understanding of students' responses from Phase I, we will design protocols that build on students' ideas and provide them with experiences to help them transfer physics concepts to medical applications. This format provides a best-case teaching environment for both teacher-student and peer interactions. Frequently, the peer interactions will bring up ideas that the researchers had not previously considered.

Three layers of analysis will be used to organize information from the interview and teaching experiment data and to develop models of reasoning, transfer and understanding.

- In *Phenomenographic Analysis*[17] categories for coding of the interactions emerge from the analysis of the responses and are based on students' ideas rather than researchers' preconceptions. This strategy is consistent with contemporary notions of transfer[18] in which the researcher does not prejudge what idea a student must transfer, rather he/she looks for what, if anything, the student has transferred.

- *Thematic Analysis*[19] uses the phenomenographic categories together with the observer's field notes and reflections to determine the main themes in student understanding.
- With *Interaction Analysis* we use observation protocols to analyze the ways in which students interact with the instructional materials, teacher and each other to construct models that explain physical phenomena. We will adapt the analysis methods such as those used to assess one-on-one tutoring.[20-22]

Throughout this analysis we will use state-of-the-art video analysis software that allows for easy coding of video or audio data from interviews and classroom interactions[23] and enables a researcher to simultaneously observe several different views (video streams) of the same interview or classroom.[24] These tools will enable us to analyze a variety of teaching-learning situations and clinical interviews and build models of student reasoning and transfer.

INSTRUCTIONAL MATERIALS

The second component of this project will be the development of instructional units that introduce applications of contemporary physics to medicine. The instructional units will build on the research discussed above and previous work both in teaching physics and medical technology. They will integrate interactive multimedia with inexpensive experimental materials and written documents in an activity-based environment. The goals of this component of Modern Miracle Medical Machines are to:

- *Integrate the Learning of Applications of Contemporary Physics Into the Traditional Pre-Med Physics Course.* Modern Miracle Medical Machines will consist of individual instructional units each of which will require from two to four hours of instruction and can be inserted as students complete the study of certain classical concepts, such as conservation of energy. The materials will not require complete revision of the present curriculum and will not need to be placed at the end of the year.
- *Emphasize Hands-on & Minds-on Activities.* Small, inexpensive devices will be used as analogies to help students understand the contemporary physics principles or as analogs to diagnosis procedures.

- *Combine Written Materials and, Interactive Multimedia.* All types of learning materials are needed to provide an adequate learning environment for the study of application of contemporary physics. Paper and pencil as well as various digital formats will enable students to explore phenomena such as positron emission tomography and magnetic resonance imaging.
- *Utilize Visualization Techniques.* Interactive computer visualizations and animations provide graphical descriptions of the contemporary physics underlying the medical applications as well as the applications themselves. The computer solves the difficult equations and displays the results visually. Students learn to interpret and explain these graphics.

We expect the instructors to desire flexibility in how the materials are adapted to their classes. Thus, we will create modules which can be covered in one-to-three class periods. Each unit will be relatively self-standing with references to common textbooks. Instructors will be able to pick modules which best fit with their course goals and easily work them into existing courses.

We believe that the curriculum integration strategy that has the best chance of success is the use of substitution units and not through an expansion of the topics covered in the class. Substitution units in this case would be *Modern Miracle Medical Machines* modules that could be used in place of other existing instructional materials. For example, a lesson on the use of time of flight in positron emission tomography can be taught as a substitute for traditional examples which relate velocity, distance and time. Likewise, ultrasonic imaging of a fetus can be substituted for the standard discussion of echoes for reflection of sound.

To facilitate this integration we must provide easy ways for instructors to substitute our materials for the traditional ones. The instructors' guides will link our units to the more commonly used textbooks. In addition to information about teaching the content, instructors will be given information about transitions from the traditional material to ours and then the transition back to the next section of the traditional materials. This approach follows closely the model used for *Visual Quantum Mechanics,* which is aimed at secondary school and introductory university physics classes.

PEDAGOGICAL STRUCTURE

We will design all materials to be consistent with contemporary research on how students learn.[25-27] The pedagogical structure of *Modern Miracle Medical Machines* will be based on the learning cycle of Karplus,[28] as modified into the modeling cycle by Wells, Hestenes & Swackhamer.[29] Each of the units will begin with an exploration in which students investigate the phenomena to be studied before a formal introduction of the concept. Whenever possible, these explorations will involve hands-on activities with simple equipment or devices. As much as we can, we will create explorations that could be completed on the desktops of a normal classroom or in the homes of the students. If such experiments are not available, we will create explorations by using interactive multimedia.

During the concept introduction the teachers or the materials will present the concept that is related to the exploration activity. Following the introduction of the new concept the students will be guided to build models that help them understand the phenomena that they have encountered during the exploration by applying the newly learned concept. These models of nature and of the medical procedure will help students transfer their new physics knowledge to the context of medical diagnosis or treatment.

Finally, an evaluation of the students' understanding of the new material will conclude each unit. However, we will develop materials that go beyond the traditional evaluation of a test at the end of the unit. We will include suggestions for experimental design activities and for topics and activities which could be included as part of a portfolio.

DEVELOPMENT PROCESS

Our approach to designing and creating instructional materials will be based on contemporary research on the curriculum design process. Following Wiggins and McTighe[30] we will first identify the desired results, then determine acceptable evidence (assessment) that these results have been achieved and, finally, design and create the learning materials.

All instructional materials will be pilot-tested with students in clinical and classroom settings. First, small groups of students will complete each instructional unit module in an environment similar to the teaching interview described in the research section above. Then, pilot tests will be conducted using entire classes at Kansas State, Norfolk State University and the University of Texas at El Paso. Following these initial tests, we will make the materials available for testing throughout the country.

As we seek field testers beyond the first three universities we will simultaneously be developing a cadre of faculty who are interested in and excited about the teaching of contemporary physics applications as part of a pre-med physics course. Thus, we will recruit a broad spectrum of teachers in terms of their background in physics, geographical location, teaching situation, gender, ethnic background and teaching style. To accomplish this recruitment we will place advertisements in journals and magazines of the American Association of Physics Teachers and, if possible, the American Physical Society's Forum on Education. Further, we have a mailing list containing the names of several hundred college and university teachers who have received information about the *Physics InfoMall*,[31] a CD-ROM database for physics teachers and *Visual Quantum Mechanics*.[4] Throughout the project we will maintain World Wide Web pages so that anyone searching the Web for information about teaching physics to pre-med students will obtain information about our efforts.

PHYSICS & MEDICAL CONTENT

Each of the instructional units will focus on some of the diagnostic or treatment tools that are available to contemporary physicians and show how basic physics principles aid in diagnosis and treatment. The resulting instructional materials will help students who are interested in medicine transfer knowledge and understand the connection between their interests and contemporary physics research. Accompanying instructors' materials will help physics teachers facilitate the learning of these materials without the need to modify completely their existing courses or to read a large quantity of the medical diagnostic or treatment literature.

The instructional units that we plan to include are summarized in Table 1 below.

TABLE 1: Summary of the proposed learning units for Modern Miracle Medical Machines

Topic	*Prerequisite*
Time of Flight, Coincidence & Positron Emission Tomography	Distance, time and velocity
Light and 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 semiconductor
Computer Tomography	Basic ray optics
Ultrasonic Imaging 1: Reflection & Transmission	Sound propagation & reflection
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

For a few units we can build on existing materials. For example, the Didaktik der Physik group at Ludwig Maximilian University in Munich has been developing instructional materials which are aimed at German secondary students and help students learn about applications of physics to the human body. One of their learning units includes interactive multimedia visualizations on CT scans.[3] We will work with the Munich group to convert their materials to use with the U.S. pre-med audience. We will also rely on textual material written for medical and general audiences.[32-35]

Most graphical presentations related to our work have been created for technicians who operate the machinery and are interested in, at most, a very superficial understanding of the underlying science. While a few animated graphics are available for people who wish to understand MRI, we have not found any that have the level of interactivity available in contemporary pedagogically sound software. Hornak has created the best available graphics that we have found for teaching the physics of MRI.[36] When possible, we will build on these materials or adapt them to our needs if we can obtain rights to the intellectual property.

As with our *Visual Quantum Mechanics* materials, the hands-on activities and visualizations will be connected by paper-pencil lessons. Students will be asked questions to which they must respond by using activities, computer visualizations and/or applying the principles of physics to the material at hand.

For this project we will involve faculty from appropriate communities in the design and development process. We will ask instructors to review a general overview for the projects, the objectives, the assessments, the proposed content of the learning units and the pedagogical design for the materials. On the basis of this planning effort the project staff will begin the design and development effort. The development of materials will be completed by the staff of the KSU Physics Education Research Group in collaboration with specialists in medicine and interactive design.

SUMMARIES OF TWO EXAMPLE LESSONS

Time of Flight, Coincidence and Positron Emission Tomography: The students can study this unit immediately after studying the relationship between distance, time and velocity. The primary goal will be to enable students to see how measurements involving relatively simple physics can lead to information concerning structures inside the body. Assessment will involve students being able to state location and relative shapes of objects from timing data. In an exploration experiment two collision carts will be released in an area that is hidden from view. The carts move away from each other through the interaction of a spring between them and then can be seen by the students. They measure the times and speeds of the carts and work backward to determine the location of the release. The concept that positrons and electrons interact to produce two or three objects that move at the speed of light will then be introduced. Students will create models using the rapidly moving objects that are emitted in a variety of directions. Computer visualization will be the application which helps the students understand how coincidence and time-of-flight were involved in recreating images with Positron Emission Tomography.

Computer Tomography (CT): The goal of this unit will be to enable students to understand how optics is important to constructing an image in a CT scan. Assessments will include reconstruction using the different techniques described below and developing ideas on how similar techniques could be used in other applications such as airport security. As an analog to CT, they will shine a laser into a region that contains an object that will block light. By observing the light transmission, they will reconstruct the approximate location and shape of the object. The exploration will be repeated with an object that transmits some of the light. The concept introduction and modeling will lead from simple ray optics to filtered back projection. A first application will extend the idea further for students as they investigate light passing through a 2X2 matrix of materials. Each element in the matrix will be a square plastic container holding colored water – red, blue, yellow and clear. This analogy uses visible light with small volumes (called voxels) and food coloring as the absorbing material. Using only four voxels in an activity, students model the basic concept behind the algebraic reconstruction technique of CT. A computer simulation can be created to scale-up the experiment to a number of voxels that is closer to the number in a real patient. Then, with interactive visualizations students can be led to the Fourier transform method of computed tomography and thus to the real methods used in modern radiology.

EVALUATION

The Office of Educational Innovation and Evaluation (OEIE) at KSU will serve as the evaluators on the project to conduct both formative and summative evaluation, as well as provide information for NSF reporting. OEIE's principal evaluators have conducted program evaluations for numerous state and national funded projects and have extensive expertise in program evaluation design, curriculum development, faculty training, instrument development and assessment of educational programs. For this project OEIE will focus on the evaluation of the instructional materials.

Strategies for assessing the project's effectiveness will focus on both formative and summative evaluations that will utilize mixed-method approaches (qualitative and quantitative) that include observation, rubrics, performance assessments, web-based surveys, interviews (some via telecom) and focus groups. The plan identifies the indicators, benchmarks, methods and timeline that guides the evaluation and is consistent with the NSF and other professional guidelines.[37,38]

The formative evaluation of the instructional materials will have several steps. First, after both internal and external reviewers have worked through the materials, we will ask several local students to complete each unit. Revisions will be made as necessary and then the materials will be available for limited field-testing. Each field test student and instructor will complete survey instruments constructed by OEIE and conceptual tests constructed by the development team. These materials will help us assess both attitudes and learning. All results will be reported to and analyzed by OEIE. Appropriate revisions will follow. Then, OEIE will work with instructors to obtain information about how the materials worked in their classes and to administer questions on the effectiveness of materials.

The evaluation will document the impact on both attitudes and learning of students, teachers and faculty. Instructional materials will be developed and reviewed by the physics community and then field tested, modified based on preliminary findings and then re-administered for further examination and modification for national dissemination.

DISSEMINATION

The dissemination of research results will be through publication in appropriate journals. For the instructional materials we will follow a pattern that we have used in disseminating innovative instructional materials over the last 20 years. During the development phase we will use the evaluation and field testing of the materials to build interest in the project as described above. At that time all major documents and software will be available on our Web site for interested instructors to use. We will work closely with the dissemination efforts of the *Humanized Physics* project to take advantage of our dissemination efforts. As the project nears completion we will seek a form of publication that will assure wide distribution and a means to return some funds to the project for future upgrades. Most likely we will work with the publisher of *Humanized Physics* which will reach completion a couple of years before we do.

We expect that the final products will be a set of printed materials and one or more CD-ROMs (or whatever the means of electronic distribution is in four years) which contain computer programs, some hypertext documents, teachers' information, electronic copies of the printed materials, a collection of low-cost equipment and possibly some digital video movies. If publishers have found ways to distribute through the Web, we will work with them. If not, we will work to create an efficient way for more traditional distribution. Based on our previous experiences we anticipate no difficulty in finding a company that would be interested in distributing our materials.