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CONTEMPORARY PHYSICS FOR FUTURE TEACHERS WITH LIMITED MATHEMATICS SKILLS

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ABSTRACT

Many areas of the United States face shortage of teachers who have studied a significant amount of physics at the university. To provide secondary school students with a course in physics many states allow teachers of other sciences and mathematics to become physics teachers. These teachers must complete some minimal number of physics courses at the university. To help these teachers understand contemporary physics we have designed a course which future secondary science teachers complete. The course relies on computer visualization and hands-on activities rather than mathematics to convey the concepts of quantum mechanics and other related topics.

1. INTRODUCTION

"High school physics teachers in short supply," reads a front-page headline on the March 2000 issue of the *American Physical Society's News*. The accompanying story and graphic (Figure 1) provides documentation for a serious concern. High school physics teachers are not being graduated from U.S. Colleges of Education at a rate that is sufficiently high to meet the demand. Further, a fully trained high school physics teacher is also a well-educated scientist. Thus, when the frustrations of school teaching become slightly too much, the physics teacher can easily find another position, which is frequently better paid. As a result, a very large fraction of the instructors who teach high school physics are teachers of other sciences, mathematics, and other subjects and have been pressed into service in the physics classroom.

To provide secondary school students with a course in physics many states allow teachers of other sciences and mathematics to become physics teachers. These teachers must complete some minimal number of physics courses at the university. For example, in Kansas a teacher of another science or of mathematics can become licensed to teach physics by completing three semester-ling university courses in physics. Typically, the future teachers complete two semesters of an algebra-based physics and need one additional course to be able to teach physics in secondary school. While this level of physics is minimal, the universities have no control over the number of courses – only the quality.

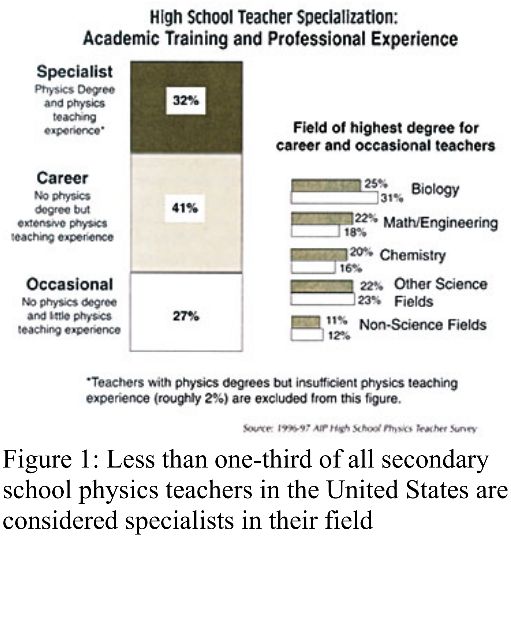

Figure 1: Less than one-third of all secondary school physics teachers in the United States are considered specialists in their field

(The requirements for teaching any subject in schools are controlled at the state, not national, level. Others states will have different requirements than Kansas. Some states require more; some require less.)

To address this issue Kansas State University's Physics Department has create a course for future secondary science teachers whose first subject is not physics. The course, Contemporary Physics, focuses on quantum mechanics and related topics. Because these students frequently have a lower level of mathematics than a typical physics student, we rely on computer visualization and hands-on activities to help the students learn these topics. At the same time we attempt to provide a role model to show the teachers how they might teach these and other science topics to their students when they become teachers.

Begun in the early 1980s Contemporary Physics presents quantum-related topics in a manner which students who have very limited exposure to physics or mathematics can understand. In addition to future teachers some students take the course to fulfill a science requirement at the University.

A major goal is to enable the future teachers and other students to understand quantum physics at level beyond that of wonder and paradox. Thus we wish to enable students to see the reasons that the paradoxes arise, to understand that some of the mystery follows logically from the fundamental assumptions, and to learn how quantum physics is reflected in their lives. To teach this course the physics education groups at KSU started creating computer programs which helped students to see visualizations of such abstract ideas as the wave function of an electron. Eventually, these early programs formed the basis for the *Visual Quantum Mechanics* [1,2] project.

2. VISUALIZATION OF QUANTUM PHYSICS

Fro a long time, books and films have attempted to bring quantum physics to an audience that is broader than the few physicists and mathematicians who understand matrix theory and differential equations. Usually these materials concentrate on the "wonders" and paradoxes of quantum theory. The reader learns that in the quantum world some of our intuition fails us, but is seldom able to obtain a grasp of the underlying principles or the reasons that quantum theories are important in our everyday life.

Visualization of complex mathematics, even when that mathematics represents the physical world, does not by itself reach our goals. We must put this visualization into a context. Thus, we have created a series of activities that involve questions to motivate the students and investigations of practical devices. For instance, in one of the activities students explore the possibility of creating a "transporter" used in Star Trek. In another activity, they discuss the merits of using light emitting diodes as a light source for growing plants in space, and in yet another activity, they use a simulation to see whether a scanning tunneling microscope can be used to manipulate individual atoms to create nanodevices. Through all these activities, we emphasize the application of quantum physics to both the practical and the possible. Thus, hands-on activities in conjunction with the computer programs enhance the context of the visualization.

3. ORGANIZATION OF CONTEMPORARY PHYSICS

The class meets three times a week in a Monday - Wednesday - Friday sequence. The desks in the classroom are arranged so that the each student can face all other students as well as the instructor. This arrangement is especially conducive to interactions between students. A classroom response system is used to solicit responses from individual students at various times during the lecture. Most of the learning in the class takes place through interaction and discussion rather than in the lecture mode.

The students' tables are also used to place any equipment needed for hands-on activities. Computers are located behind the students. When they work on computer activities the students turn to the computers. When they are discussing, listening to a lecture or using hands-on equipment, they face away from the computers and are not temped (or able to) read their e-mail. Figure 2 shows students working with a computer program and the table for book , equipment and coffee cups.

Figure 2: The classroom arrangement for Contemporary Physics.

The future teachers also complete a two-hour laboratory each week. This laboratory is used to include quantitative analysis of some of the experiments that are done qualitatively in class. Frequently the students will complete experiments that use relatively sophisticated equipment and compare those results with simulations or experiments with simple equipment. For example electron interference is completed with two different sets of apparatus. Then the students look at interactive simulations [3, 4] and video presentation of the same experiment [5]. In this way the future teachers complete experiments which are critical to the development of contemporary physics and experience ways to present these experiments to their students when the equipment of a university are not available to them.

4. INSTRUCTIONAL MODEL

To provide an appropriate learning environment and to model good teaching practice, we utilize the Learning Cycle developed by Karplus [6]. Students begin with an exploration -- sometimes exploring and observing actual events; sometimes a visualization activity using one of our computer programs. Next, in the concept introduction phase, with the guidance of the instructor, they attempt to construct a model that can explain their observations. Finally, in the application phase they perform one or more activities in which they utilize their model in a specific context.

Very often at least two possible pedagogical outcomes arise through the above learning process. First, while constructing the model students have to make simplifying assumptions which they are compelled to verify later. Second, the context in which they apply the model may lead them to explore new phenomena. In either case, the students are motivated to proceed in their search to a higher level of understanding of quantum physics. The learning cycle is thus repeated.

An important effect of using the pedagogical structure described above, is that it is exemplary for students in the class who will be future high school physics teachers. Many of the activities and materials that the students use are also available in most high schools.

5. COURSE CONTENT AND INSTRUCTIONAL MATERIALS

Various topics in the Contemporary Physics course are interconnected by a common thread of ideas. The observations made or concepts developed in one activity, motivates the next.

The course begins with review conservation laws that they may have studied in a pervious course. Unlike traditional courses where conservation laws are simply stated and then applied to solve problems, here students learn how conservation of various these laws can be used to learn about objects that are not visible to the naked eye. A simple classroom demonstration where students guess the shape of a hidden object on the basis of ping-pong balls that bounce off it put these laws in context

We begin the study of contemporary physics be emphasizing that we can learn much about things we can not see for watching the results of interactions and applying conservation laws to the observations. Because developing a model of the atom would appear to be a rather esoteric goal from the students' perspective, it is not directly stated as one of the goals of the activities to follow. Rather students are motivated to study the light emitting diode (LED), which is present in most modern electrical appliances as an indicator light. Students learn how the LED works, construct a model of the atom, and apply it to gases and solids.

The students begin with a hands-on experiment in which they investigate the electrical properties of several light emitting diodes (LEDs). They discover that these light sources have several unusual properties:

- The voltage at which they turn on depends on their color.
- Unlike regular lamps the LEDs do not start dim and get brighter; they are either on or off.
- Current can pass through them in only one direction.
- They emit colored light even though they are made of clear material.
- The colors emitted by each LED are only a small part of the visible spectrum.

Trying to explain these observations with existing knowledge is difficult at best, so the students are motivated to learn more about sources of light. Because the LED is a solid, and solids are likely to be more complex than gases due to their closely packed atoms, the students are persuaded to learn more about gaseous light sources.

The students look at the light spectra emitted by a number of gas lamps, both in the laboratory and on street corners, using simple hand-held spectroscopes. From their observations of the light patterns of various gases, and using a computer program (See Figure 3), students construct a model of light emission from an individual gaseous atom. Then using other programs, they extend this model to solids and explain the light patterns emitted by LEDs.

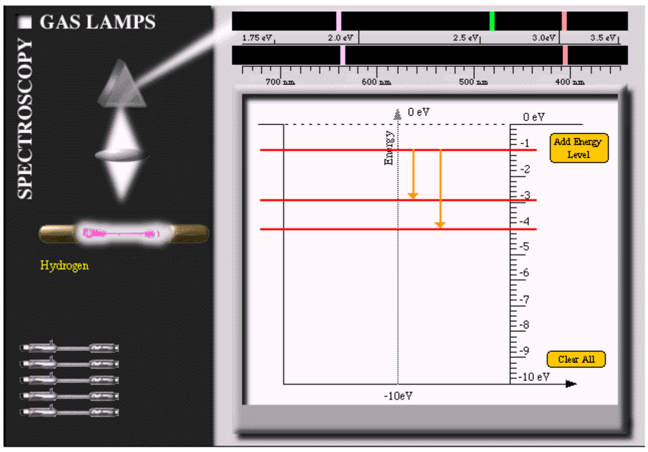

Figure3: The *Gas Spectroscopy* program from *Visual Quantum Mechanics* enables students to construct an energy level model of an atom.

Some of the electrical properties of the LED, however, are not yet explained. So, the students return to their original experiment and a simulation (See Figure 4). This program allows them to simulate the electrical characteristics and at the same time watch a visualization of the changes in energies of the electrons in the solid. With this information they can understand all of the properties of light emitting diodes.

Along the way students learn that these devices, which require quantum physics to understand, are small and use much less energy than other light sources. Thus, they would be good for light sources to grow plants in a space station. The students are asked to use their knowledge of how solids emit light and design the solids that would provide the correct spectrum for plant growth. This topic is a subject of present-day research.

The concepts that the students have developed to explain an LED can also be applied to explain the colors and spectra of light sticks and other luminescent objects. Students observe the light emitted by some of these objects and their changes with temperature. They learn about the different forms of luminescence and investigate at least two of these in greater detail. As an application activity in this set, students construct a model of the infrared detector card that is commonly used by TV repair technicians to check if the remote control works. The investigation of each device includes hands-on experiments and building a model with a simulation program, similar to the one presented in Figure 4.

The activities and programs leave at least one important question about their energies unanswered: Why are only certain energies allowed in atoms? Hence, students perform another set of activities that introduce the wave representation of matter. Eventually the students learn to sketch wave functions qualitatively. Programs such as the *Wave Function Sketcher* (Figure 5) help the students with making the sketches and interpreting the results.

Finally, while students have developed a model for an atom in the preceding activities, they realize that the model is based not on a direct observation of an atom, but rather on indirect experimental data. This realization motivates discussions of present day

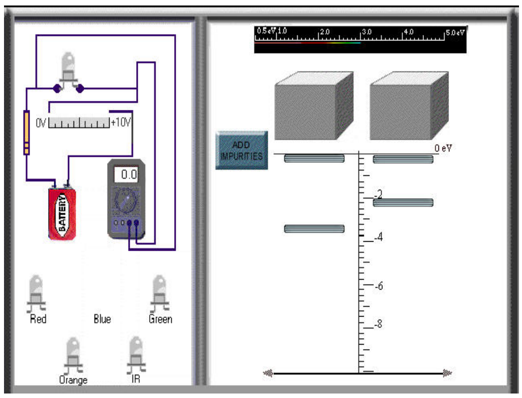

Figure 4: The *Semiconductor Constructor* program allows the students to compare their experimental measurement of the electrical characteristics of the LED with those of the simulation.

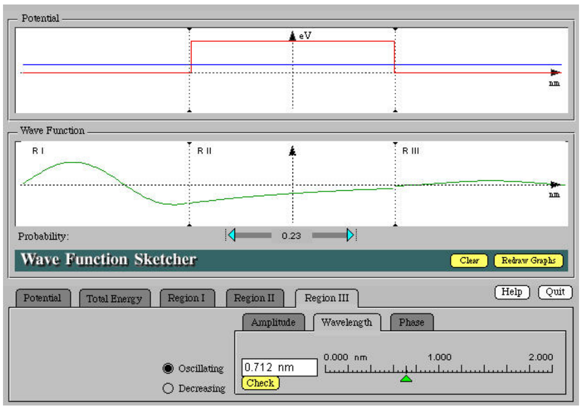

Figure 5: The *Wave Function Sketcher* helps students make qualitative sketches of wave functions and analyze the results.

technology for such direct. Students are also introduced to the field of nanotechnology, and use the Web to read more about the subject. They develop an appreciation of the usefulness of observing individual atoms and manipulating them to create nanostructures. Students are then introduced to the scanning tunneling microscope (STM): a device used to "see" individual atoms. Since a typical instructional STM is prohibitively expensive, a simulation program that we have developed enables students to learn how an STM works, and the basic quantum science that applies to it.

The study of quantum mechanics requires about 70% of the semester. Along the way we introduce many modern applications of quantum physics such as the STM, light emission and detection, and medical diagnostic instruments [7],

The remainder of the semester is devoted to a survey of nuclear radioactivity, fission and fusion. A very short introduction to cosmology is usually included during the last week.

The Contemporary Physics course was created about 20 years ago to meet the need of future secondary science teachers. Then, and today, no suitable textbooks exist for this course. Because texts are frequently used to help define goals and content, this course lacked a focus. The implementation of visualization techniques has enabled the faculty to establish a focus on basic quantum mechanics and its applications.

6. STUDENT WORK LOAD

In the language of the U.S. educational system, Contemporary physics is a one-semester, 4 credit course. The class meets for discussion and short activities 3 times per week for 15 weeks. Each of these sessions is 50 minutes in duration. During these classes lectures, student discussions and work with the visualization programs described above are integrated. Occasionally, short hands-on experiments and demonstrations occur during the class. As described above, the students who are future teachers meet for an additional two-hour laboratory session once per week. As is typical in the U.S. homework is assigned each week. Usually, the homework involves 4-5 questions which are graded by the instructor and returned to the student. Students are also required to respond to

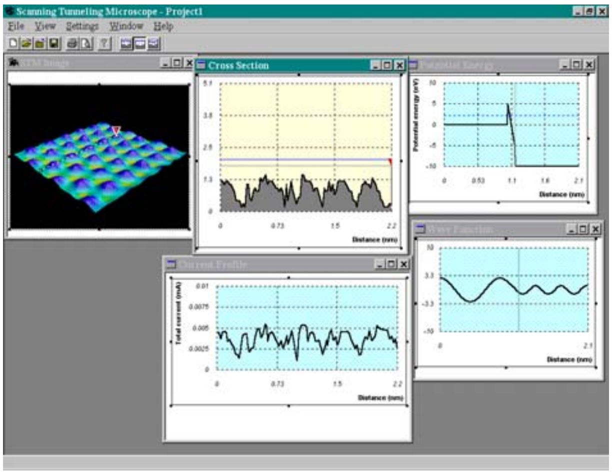

Figure 6: The *STM Simulator* program demonstrates the underlying physics of the scanning tunneling microscope.

questions about their opinions on various aspects of the course once per week. The students take four one-hour examinations during the semester and a two-hour final examination immediately after the semester ends.

7. OUTCOMES

No formal evaluation of these course materials has been completed. However, the *Visual Quantum Mechanics* materials have undergone extensive evaluation [2, 8-12]. They seem to have been very effective in reaching the goal of a qualitative understanding of quantum physics.

At an informal level, we find that the students have a very positive attitude toward both the learning methods and the subject matter. Many of the teachers report that thy do use these materials in both the teaching of physics and chemistry.

8. ACKNOWLEDGEMENTS

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