Contemporary Physics for Non-science Students :
Combining Visualization with Hands-on Activities

Dean A. Zollman (dzollman@phys.ksu.edu)

N. Sanjay Rebello (srebello@phys.ksu.edu)

Department of Physics, 116 Cardwell Hall, Kansas State University, Manhattan, KS 66506-2601

Introduction

The physics concepts that have been developed since the 1930s have been extremely successful in describing and explaining atoms and other very small objects. These theories, however, rely heavily on rather abstract mathematics that is accessible only to students who have completed several years of university-level math. Thus, most college students do not have the background to study and understand quantum physics.

In the past, several 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.

The Contemporary Physics course is an effort to address the lack of access to modern physics topics to non-physics majors. Begun in the early 1980s this course presents quantum-related topics in a manner which students who have very limited exposure to physics or mathematics can understand. Students who take the course fall into two broad categories: future teachers of math and sciences other than physics and students taking the course to fulfill a science requirement. All students in the course have completed at least one semester of classical physics. Thus, the course content must address the contemporary topics without the use of mathematics beyond the level of algebra.

A major goal is to enable 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 present in their lives. To achieve this level of understanding without the mathematics has led us to rely heavily on the use of technology and hands-on experiments. Computer programs created by our group enable students to see visualizations of such abstract ideas as the wave function of an electron. By making the programs interactive the students can change variables and learn how the various parameters and the wave function will change.

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.

General Course Organization

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, Classtalk™, 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. Often two or three students share a palm-top response computer and are asked to discuss their responses with each other before entering it. The students' tables are also used to place any equipment needed for hands-on activities. The class meets in a computer lab on days when the students need to use the computer for activities during the class.

Instructional Model

To provide an appropriate learning environment, we utilize the Learning Cycle developed by Karplus. 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.

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 a 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

The preceding discussion about subatomic particles motivates a discussion of energy changes during interactions. Students first study these interactions on a macroscopic scale. They observe the motion of a cart on a smooth track with magnets mounted both on the cart and track. The magnets interact and thus cause changes in the cart's motion. Students use these observations and conservation laws to lean how to predict the motion of objects from graphs of energy versus distance.

For the benefit of the future high school teachers the class uses both the computer interfaced equipment to complete the measurement as well as the less expensive equipment using toy cars. Students compare their results form the two set ups and a discussion about their similarities and differences ensues.

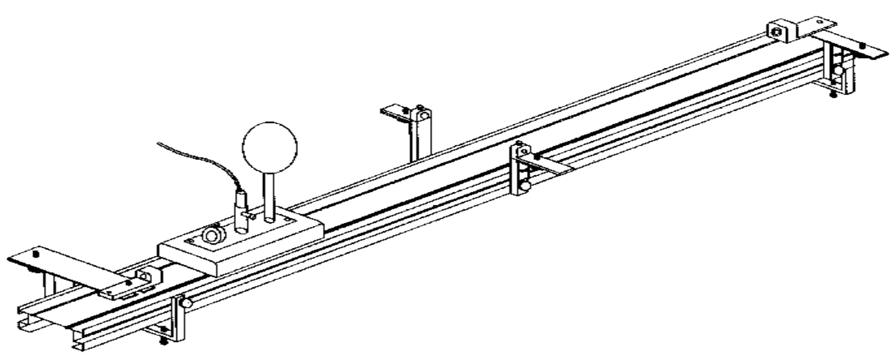

Figure 1: Set up with cart on track, used by students to study the effect of conservation laws. This experimental arrangement is used to record the distance and magnetic energy directly on a computer.

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 2), 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.

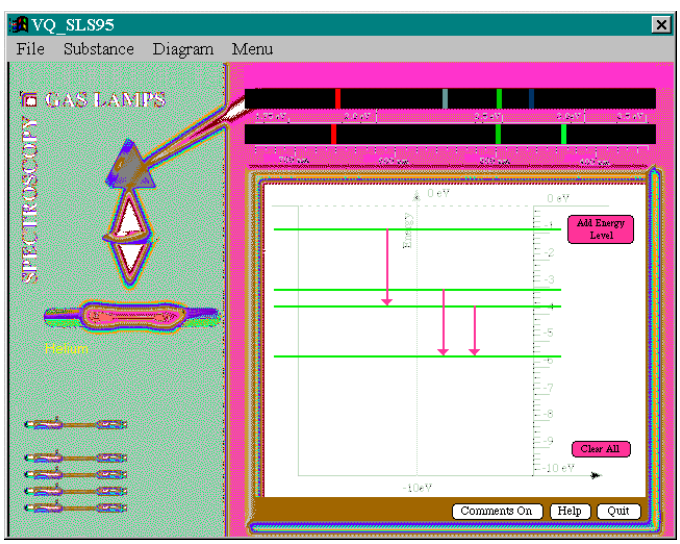

Figure 2: The *Gas Spectroscopy* program enables students to construct an energy level model of an atom.

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 3). 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.

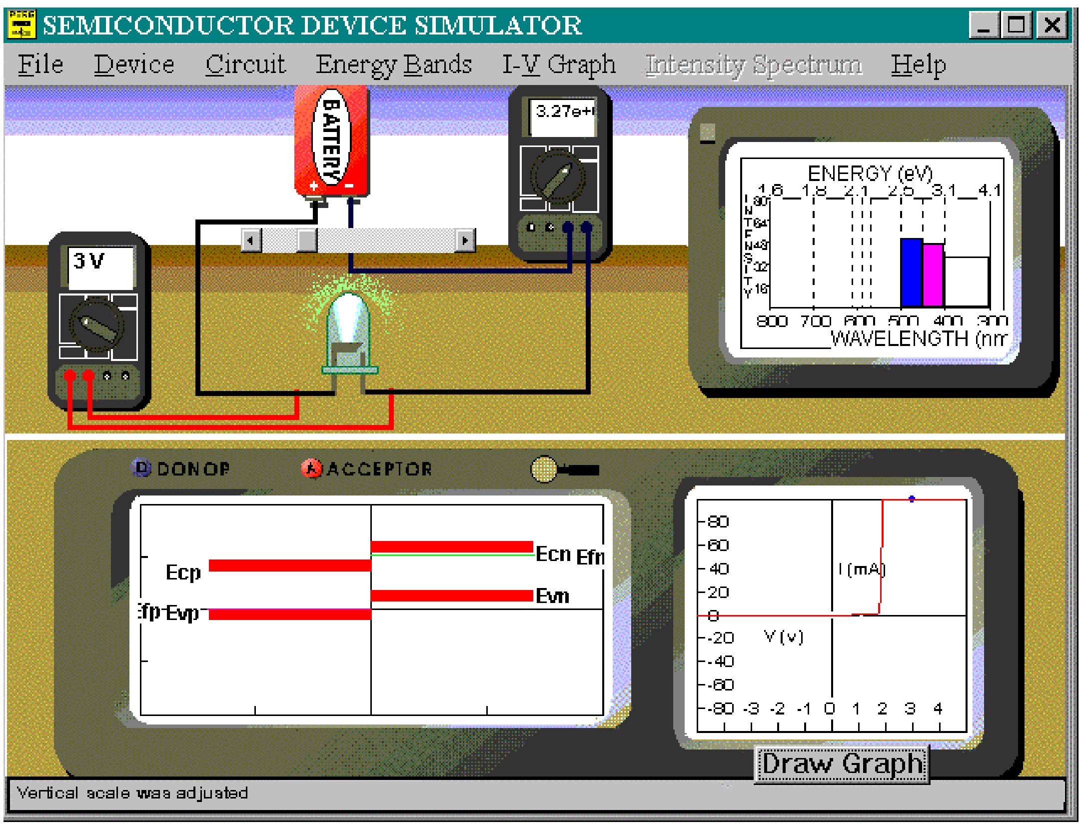

Figure 3: The *Semiconductor Device Simulator* program allows the students to compare their experimental measurement of the electrical characteristics of the LED with those of the simulation.

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 2.

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. To make this otherwise esoteric topic interesting to the students, these activities are interwoven with a discussion of the Star Trek transporter: a futuristic device which converts a material object, including a human, into energy, transmits that energy to a distant location and reassembles it. We chose this context for developing our concepts because it is particularly interesting to students who have been exposed to Star Trek and other science fiction films involving space travel. By the end of this unit, students are able to apply several concepts in quantum physics in a discussion of the feasibility of the transporter.

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 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 (See Figure 4) that we have developed enables students to learn how an STM works, and the basic quantum science that applies to it.

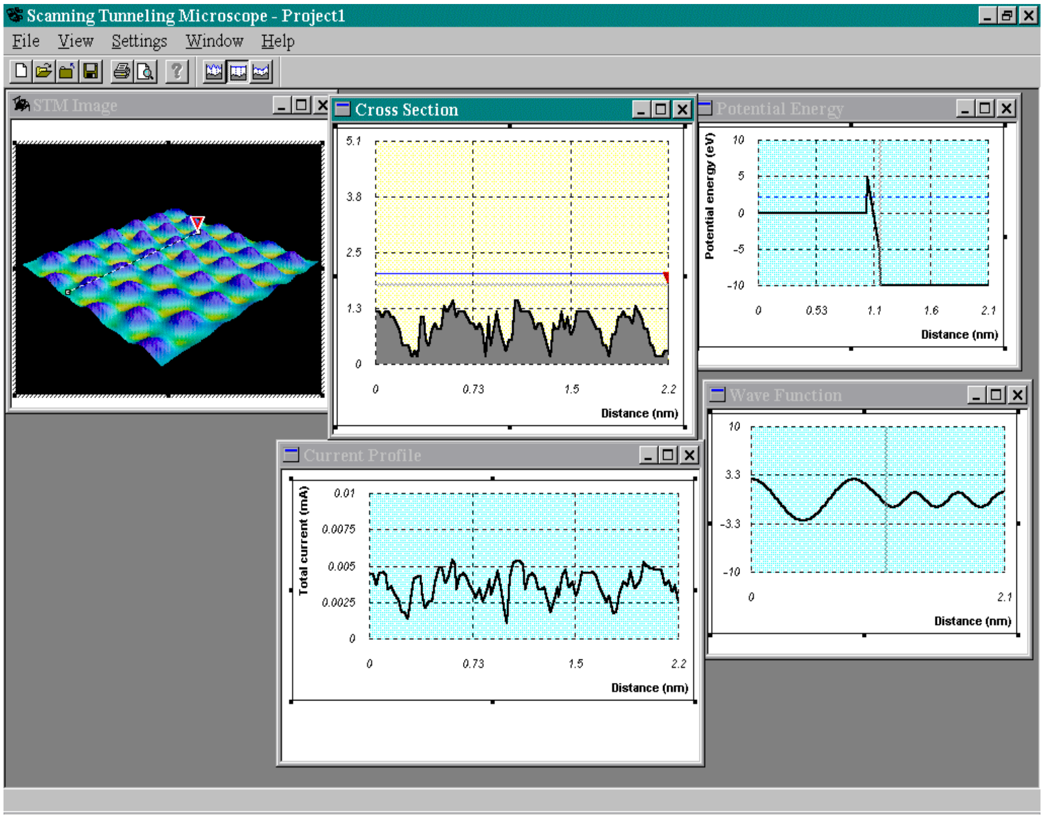

Figure 4: The *STM Simulator* program demonstrates the underlying physics of the scanning tunneling microscope.

Summary

The Contemporary Physics course at Kansas State University introduces the students to some of the most powerful ideas of 20th century physics. The material is made accessible to the introductory undergraduates by relying primarily on hands-on activities and interactive computer visualizations. Students are motivated to learn this material by demonstrating its relevance to every day life through simple devices such as the ubiquitous LED as well as futuristic ones such as the teletransporter and nanomachines.

The class is taken primarily by students majoring in sciences other than physics and by future secondary high school science teachers. The classroom layout favors close interaction among students. During most of the time in the class the students work in groups on hands-on activities or interactive computer programs. They often respond to questions by the instructor on a classroom response system.

The Learning Cycle serves as an appropriate pedagogical structure for the course because it lends itself to the constructivist paradigm of learning that we emphasize through example especially for future high school teachers who are students in the course. Students are motivated to think and learn by placing these interactive tools in the context of present day and futuristic devices that use quantum physics.

At the high-tech end of the technology scale students use computers to draw potential energy diagrams, create energy bands, construct LEDs, sketch wave functions, or simulate an STM. At the other end of the spectrum the students explore seemingly simple devices such as ordinary lamps, chemical light sticks, toy cars on ramps, bouncing springs and wave machines.

The high-tech and low-tech are brought together when the students use software visualizations to develop models at the level of an atom to understand the observations of the simple devices. Thus they begin to understand and appreciate the mystery and fascination that pervades the realm of 20th century physics.