INVESTIGATING THE APPLICABILITY OF ACTIVITY-BASED QUANTUM MECHANICS IN A FEW HIGH SCHOOL PHYSICS CLASSROOMS

by

LAWRENCE TODD ESCALADA

B.S., Kansas State University, 1988
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A DISSERTATION

submitted in partial fulfillment of the

requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Curriculum and Instruction
College of Education

KANSAS STATE UNIVERSITY
Manhattan, Kansas
1997

Approved by:

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ABSTRACT

Quantum physics is not traditionally introduced in high school physics courses because of the level of abstraction and mathematical formalism associated with the subject. As part of the *Visual Quantum Mechanics* project, activity-based instructional units have been developed that introduce quantum principles to students who have limited backgrounds in physics and mathematics. This study investigates the applicability of one unit, *Solids & Light*, that introduces quantum principles within the context of learning about light emitting diodes. An observation protocol, attitude surveys, and questionnaires were used to examine the implementation of materials and student-teacher interactions in various secondary physics classrooms.

Aspects of *Solids & Light* including the use of hands-on activities, interactive computer programs, inexpensive materials, and the focus on conceptual understanding were very applicable in the various physics classrooms observed. Both teachers and students gave these instructional strategies favorable ratings in motivating students to make observations and to learn. These ratings were not significantly affected by gender or students' attitudes towards physics or computers.

Solids & Light was applicable in terms of content and teaching style for some teachers. However, a mismatch of teaching styles between some instructors and the unit posed some problems in determining applicability. Observations indicated that some instructors were not able to utilize the exploratory instructional strategy of *Solids & Light*. Thus, *Solids & Light* must include additional support necessary to make the instructor comfortable with the subject matter and pedagogical style. With these revisions, *Solids & Light*, will have all the key components to make its implementation in a high school physics classroom a successful one.

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CHAPTER 1
INTRODUCTION

1.1 Technology and Quantum Mechanics

With each passing moment, our standard of living becomes more dependent on the latest developments in science and technology including everyday devices such as computers, cellular phones, and laser scanners found at the checkout counters of grocery stores. These developments have and will continue to have profound effects on our society. As a result, the scientific and technological literacy of the populace must be at a level that enables all citizens to maintain their standard of living and make educated decisions on science- and technology-related issues as well as on everyday applications of the latest developments in science and technology.

To keep pace with modern technology, to meet the needs of society, and to make sound decisions regarding the applications of the latest developments in science and technology, female and male students from all cultural and socioeconomic backgrounds need to have, at the very least, a general understanding of the physical phenomena responsible for these applications and the fundamental physics principles that explain this phenomena. These fundamental principles are in a branch of physics called quantum mechanics or quantum physics. Quantum mechanics provides a basis of understanding of our world from a microscopic perspective (Morgan & Jakovidis, 1994). Hobson (1996) prefers the term “quantum physics” over “quantum mechanics” because he believes the latter is an inappropriate holdover form Newtonian or classical mechanics. According to Hobson, although a machine might be an appropriate metaphor for the classical universe, the essence of quantum physics (or quantum theory) is its non-mechanical nature.

While classical mechanics focuses on Newton’s laws in explaining physical phenomena that occur in the macroscopic universe, quantum mechanics focuses on probabilities and uncertainties in explaining physical phenomena that occur in the microscopic universe. The key non-Newtonian idea behind quantum mechanics is that nature is discontinuous or quantized (broken into discrete quantities) at the microscopic level and that the key quantum particle to the entire high-tech world is the electron (Hobson, 1996). At the microscopic level, Newtonian mechanics, unlike quantum mechanics, fails to predict accurately physical phenomena and can no longer be used to explain the inner workings of nature.

Quantum mechanics enables us to determine the sizes, shapes, and energies of atoms and molecules; the properties of solids, liquids, gases; and the emission, absorption, and scattering of light by matter (Weisskopf, 1975). According to Weisskopf, almost all terrestrial physical phenomena are the consequence of the electrical interactions between electrons and nuclei and of the gravitational interactions between massive objects. An understanding of quantum mechanics can provide tremendous insights into these interactions and thus the inner workings of nature.

Quantum mechanics is deeply involved in the physical phenomena that we experience in our everyday life and is utilized in modern science and technology (Hobson, 1996; Johnston et al., 1996). Quantum mechanics can explain the operation and properties of novelty objects such as "glow-in-the-dark" toys, light sticks, and black lights; everyday devices such as fluorescent lamps, light emitting diodes (LEDs) found in electronic devices, and laser scanners found at the checkout counter of the grocery store; and state-of-the-art devices such as scanning tunneling microscopes (Escalada, Rebello, & Zollman, 1996a; Escalada, Rebello, & Zollman, 1996b; Rebello & Zollman, 1996).

In modern electrical devices such as computers, VCRs, television sets, cellular phones, and ATM machines, the speed and complexity of operations involved are increasing as the chips that control these operations are getting smaller and smaller. A typical personal computer today can do about 50 million operations a second (Intel, 1996). Circuits now contain wires and transistors that measure less than one millionth of a meter which is less than 1/100th the width of human hair. Thus, a computer chip can contain millions of transistors and other electronic components. As technology focuses on smaller components, their operation and properties will be increasingly governed by quantum mechanics (Lloyd , 1995; Rockler, 1991).

Because students see and use everyday devices which owe their existence to quantum mechanics, students at all levels of physics should at least be introduced to the powerful ideas and concepts used to explain the properties and operation of these devices (Jones, 1991). Future engineering and science undergraduates, who will be designing these devices, will especially need to learn quantum mechanics early in their academic career (Johnston & et al., 1996). The addition of quantum mechanics to the traditional introductory physics curriculum would give students opportunities to apply the fundamental concepts of quantum mechanics to their everyday experiences. As a result, students would have the opportunities to understand the importance and relevance of physics to their lives as well as to increase their scientific and technological literacy. Unfortunately, many teachers still exclude presenting the topic in introductory physics courses or spend very little time covering it (Hobson, 1996; Pfeiffenburger & Wheeler, 1984).

1.2 Quantum Mechanics and the National Science Education Standards

The desire to add modern physics topics to the secondary physics curriculum is reflected in the views held by the American Association of Physics Teachers (1988) and in such reform efforts as the *National Science Education Standards* (NRC, 1996). The *National Science Education Standards* and the American Association of Physics Teachers recommend that a high school physics curriculum should:

- focus on a few fundamental themes or concepts (i.e. structure of the atom, structure and properties of matter, and interactions of energy and matter),
- apply physics to applications in everyday life, technology, and related sciences,
- be appropriate, interesting, and relevant to the students' lives, and
- emphasize inquiry and the use of technology in the classroom.

The *National Science Education Standards* also recommend that a high school physics curriculum should:

- incorporate active learning in the form of "hands-on" and "minds-on" activities that allow students to take responsibility for their own learning,
- allow students to have access to easy, equitable, and frequent opportunities to use a wide range of equipment, materials, supplies, and other resources for experimentation and direct investigation of phenomena, and
- focus on collaborative learning.

The approach of focusing on a few fundamental concepts, commonly known as the "less is more" approach, should be adapted in teaching physics to give students time to develop concepts, think, reason, and perceive relationships (Arons, 1990). McDermott (1993) and Arons (1990) agree that if the objective is for students to achieve conceptual understanding, the volume and pace of coverage that have escalated in all physics courses must be cut back. McDermott warns that if students do not have opportunities to form conceptual models on which to base predictions, they will go back to using intuition and equations without any conceptual understanding of physics. Students would be restricted to frantically and aimlessly searching through the text for the right equation to use in order to solve a problem without really understanding the "physics" behind the problem.

Arons (1990) and the American Association of Physics Teachers (1988) caution that adding topics such as quantum mechanics to the existing physics curriculum would result in inadequate coverage of traditional introductory physics topics. Arons suggest that the solution is to identify a few fundamental concepts from the traditional physics curriculum that would allow students to understand the investigations and concepts that defined the electron, atomic nucleus, and the photon.

Because quantum mechanics focuses on the microscopic perspective of matter, the "less is more" approach in teaching physics is very conducive to including it to the curriculum especially if the focus is on such broad themes as the structure of the atom, structure and properties of matter, and interactions of energy and matter that are recommended by the *Standards* and the American Association of Physics Teachers.

Incorporating the applications of physics in everyday life, technology, and related sciences in the secondary physics curriculum would increase the importance and relevancy of physics. Since the operation and properties of everyday devices can be explained by quantum mechanics, the introduction of the subject into the curriculum would allow all students to utilize concrete experiences with these devices to help develop conceptual understanding of quantum principles.

1.3 Current Status of the High School Physics Course

High school physics courses are predominantly algebra-based and at the introductory-level. According to a 1989-90 nationwide survey of high school physics teachers, seventy-three percent of the physics high school courses being taught in the U.S. are algebra-based and at the introductory level (Neuschatz & Alpert, 1994). Ten percent of the physics high school courses being taught are conceptual physics, 12% are honors, and 5% are Advanced Placement physics in the second year. Conceptual physics is a physics course that typically is offered to those students who do not have a strong mathematical background and who take physics as a general survey science course. Advanced Placement physics is a physics course that offers students the opportunity to pursue and receive credit for an introductory college-level physics course based on their performance on an examination taken at the end of the school year.

Since the majority of high school physics courses are algebra-based, the students enrolled in these courses would not have the mathematical background necessary to understand quantum mechanics which is traditionally taught with a high degree of mathematical formalism. The problem is even more pronounced because physics teachers have indicated that one of their most serious concerns was that their students' lack adequate mathematical preparation (Neuschatz & Alpert, 1994). If students' knowledge of algebra is not enough to learn quantum mechanics, students with sub-par algebra skills will definitely be left out in the cold when it comes to learning quantum mechanics in the traditional manner.

In addition to inadequate student mathematical preparation, secondary physics teachers characterize the following as the most serious problems in their classrooms (Neuschatz & Alpert, 1994; Weiss, 1994; Baird et al., 1994):

- insufficient funds for purchasing equipment and supplies,
- inadequate laboratory facilities,
- students who think physics is not important or relevant to their lives,
- lack of appropriate computer software and interfacing devices,
- lack of materials for individualizing instruction, and
- limited access to computers.

These problems faced by secondary physics faculty could hinder a teacher's ability to follow the guidelines as suggested in the *National Science Education Standards* and by the American Association of Physics Teachers and to introduce topics like quantum physics in their classrooms. The lack of the appropriate and necessary resources can to a large degree determine whether or not a topic like quantum mechanics will be introduced especially if the topic is not required in the traditional high school physics curriculum.

Teaching modern physics accounts for less than 10% of the total class time in high school physics courses (Neuschatz & Alpert, 1994; Pfeiffenburger & Wheeler, 1984). Pfeiffenburger and Wheeler surveyed physics teachers from 110 schools in a variety of settings (i.e. public, private, rural, suburban, urban) in 39 states. They found that the majority of class time in a physics classroom was spent on mechanics (36%), electricity and magnetism (20%), optics and waves (20%), and heat and kinetic theory (13%).

Neuschatz and Alpert (1994) surveyed secondary physics teachers in regards to the amount of class time devoted to various physics topics. The results of this survey, found in Table 1-1, indicate that the majority of class time was spent on mechanics (about 40%) and less than 10% of class time spent on modern physics.

Table 1-1: ***Class Time of Secondary Physics Courses Devoted to the Following Topics***

Topics	Regular First Year Physics	Conceptual Physics	AP Physics*
Mechanics	37 %	40 %	39 %
Electricity & Magnetism	17 %	17 %	29 %
Optics & Waves	17 %	17 %	11 %
Heat & Kinetic Theory	11 %	10 %	7 %
Modern Physics	7 %	5 %	9 %
Other Areas	12 %	12 %	5 %

*Includes non-AP 2nd year physics

Pfeiffenburger & Wheeler (1984) found that of those high schools that offer a physics course, 22% of the physics teachers do not teach modern physics and 27% of the physics teachers devote 5% of class time to teaching modern physics. These percentages and the ones found in Table 1-1 reflect the focus on mechanics in the traditional high school physics course and the lack of emphasis on contemporary physics topics.

The amount of class time devoted to modern physics in the Advanced Placement physics (non-calculus) course comes close to matching the percentages indicated by the Pfeiffenburger and Wheeler study. Atomic physics and quantum effects (not including nuclear physics and special relativity) account for only 9% of the Advanced Placement Physics (non-calculus) course, while mechanics accounts for 33%, electricity and magnetism accounts for 25%, waves and optics accounts for 15%, and heat and thermodynamics accounts for 10% (College Board, 1995).

In regards to the recent developments and the applications of physics to everyday life (which could be discussed in quantum mechanics), teachers in general feel unprepared to teach these topics and feel they need to update their knowledge on the applications of science and technology (Neuschatz & Alpert, 1994; Baird et al., 1994). A *National Survey of Science and Mathematics Education* found that high school science teachers believe that applications of science to daily life, hands-on activities, concrete experiences coming before abstract treatments, and use of computers are very important strategies to incorporate in the classroom (Weiss, 1994). These strategies are very consistent with recommendations made in the *National Science Education Standards* and by the American Association of Physics Teachers.

Obviously, high school physics needs to be seen as important and relevant by students. Quantum physics can serve as a mechanism to increase the relevance of high school physics since it can be used to explain the properties and operation of everyday devices. Based on the amount of class time devoted to contemporary topics, however, inadequate time is available to simply "tack on" quantum physics to the syllabus at the end of the semester. A practical and pedagogically sound solution would be to integrate quantum physics into the existing curriculum by focusing on a few a fundamental physics concepts that are typically taught in a traditional introductory physics course.

1.4 Difficulties Associated with Teaching Quantum Mechanics in the High School

Because of the abstract nature and mathematical formalism associated with the subject, physics has typically been one of the science disciplines that students associate with being beyond their comprehension (Escalada, Baptiste, Rebello, & Zollman, 1997). The mathematical formalism and abstract nature, which is especially associated with quantum mechanics, contribute to the difficulty of understanding quantum concepts (Johnston et al., 1996; Morgan & Jakovidis, 1994). The difficulty of learning quantum mechanics is reflected by the statement made by the physicist Niels Bohr who said "Anyone who can contemplate quantum mechanics without getting dizzy hasn't properly understood it.".

According to Strnad (1981), the difficulty in understanding quantum mechanics by students in the secondary and university settings is not only the result of the lack of an adequate background knowledge of mathematics but also a lack of adequate knowledge of classical physics (Strnad, 1981). Fischler & Lichtfeldt (1992) attribute the difficulty of learning quantum mechanics to the problems of reducing difficult, abstract concepts into simpler, concrete concepts. Niedderer, Bethge, and Cassens (1990) include in the learning difficulties of quantum mechanics the students' inexperience in looking at the material world from a perspective that requires the use of abstract models. In thinking about quantum mechanics students most move from models that are based on sensory experiences toward models that involve abstract properties.

Some physics educators believe that topics like quantum mechanics and relativity require so much abstract reasoning with so little direct observation of physical phenomena that they are beyond the abilities of the majority of introductory students (Laws, 1991a; Arons, 1990). As a result, these educators recommend that these topics like quantum mechanics should be avoided in introductory physics courses.

If quantum mechanics is to be introduced in introductory physics courses, instructional strategies should be identified to make the understanding of quantum physics easier and possible. Because quantum mechanics focuses on the microscopic world of particles and their interactions that cannot be easily seen or made visible, Golab-Meyer (1991) suggests that analogies and models should be used to explain physical phenomena. Morgan and Jakovidis (1994) recommend that the use of simple examples should be used at the introductory level to illustrate the application of formalism to a wide range of systems and phenomena (Morgan & Jakovidis,1994).

The learning of quantum mechanics should incorporate strategies that allow students to visualize physical phenomena that are not possible with direct observation. To help students make sense of science concepts, Clement (1977) recommends that teachers must represent these concepts in multiple modes (e.g., verbal, mathematical, concrete-practical, and pictorial) and then assist their students in translating from one mode of representation to another. Computers can easily and quickly facilitate the representation of physics concepts and phenomena in variety of modes. The use of computers and computer programs that utilized a variety of techniques such as simulations, models, real-time graphs (graphs displayed at the same time physical data are being collected), and video would allow students to visualize phenomena that otherwise would not be possible (Escalada & Zollman, 1997; Escalada, Grabhorn, & Zollman, 1996). These computer techniques would also provide opportunities to develop and reinforce student conceptual understanding of abstract physics concepts within the context of concrete and relevant experiences. By using computers in the physics classroom to facilitate the incorporation of multiple instructional strategies, the instructor would also promote a personalized learning environment in which all students are interacting with the computers, teacher, and with one another. Interactive computer programs have been shown to be especially effective in activity-based learning environments to provide concrete learning experiences, improve student attitudes toward learning, and to improve student conceptual learning (Escalada, Baptiste, Rebello, & Zollman, 1997; Laws, 1991b).

In addition to the instructional strategies that utilize student interactions with the computer, instructional strategies that focus on student interactions with everyday objects and phenomena would provide concrete experiences for students to learn quantum principles. Since quantum mechanics can explain the inner workings of everyday, modern devices (Escalada et al., 1996a; Escalada et al., 1996b), instructional strategies that include student interactions with these devices would also provide opportunities for students to understand the relevance of quantum principles and phenomena to their everyday lives.

The focus on student interactions with computers and everyday, modern devices to introduce students to quantum principles and phenomena is consistent with the recommendation of the *National Science Education Standards* (NRC, 1996) to utilize instructional strategies that allow students to be actively involved in the construction of their own knowledge based on their prior experiences.

1.5 Visual Quantum Mechanics

The *Visual Quantum Mechanics* project, which is undertaken by the Kansas State Physics Education Research Group, involves the development of instructional units to introduce quantum principles to high school and introductory college students who do not have a background in quantum mechanics, algebra, trigonometry, or other higher level mathematics skills. To reach these students, the instructional units integrate interactive computer programs with inexpensive materials and written documents in an activity-based environment. The overall efforts of *Visual Quantum Mechanics* are to:

- utilize visualization techniques rather than knowledge of higher level mathematics,
- integrate the learning of quantum mechanics into the traditional physics curriculum,
- apply a learning strategy in which students actively construct knowledge, and
- utilize inexpensive materials to illustrate the application of quantum principles to physical phenomena and modern technology.

The units utilize a qualitative knowledge of a few concepts discussed in a traditional physics curriculum to reinforce students' understanding of these basic concepts at the same time that these students are being introduced to quantum principles and phenomena. This qualitative approach is consistent with the "less is more" approach recommended in the *National Science Education Standards* and by the American Association of Physics Teachers. By focusing on the qualitative approach rather than the mathematical formalism and abstractions, the relevant aspects of quantum mechanics can be emphasized and the essential factors which govern the process can be recognized to allow direct access into the workings of the laws of nature (Weisskopf, 1975).

The instructional model utilized in these units is a modified version of the learning cycle (Zollman, 1990) which was originally developed by Robert Karplus and his colleagues (Karplus, 1977). In a typical learning cycle an instructional unit would begin with a hands-on activity enabling students to make observations prior to the introduction of a new concept. An application activity follows the introduction of the new concept. The components of the learning cycle utilized in these instructional units are slightly modified:

- **Exploration**: Students perform simple experiments to investigate the properties of a physical phenomena,
- **Concept Introduction**: Within the context of the exploration and with the help of interactive computer programs and the instructor, students construct a physical model (Wells et al., 1995) consistent with quantum principles that explains their observations, and
- **Application**: Students apply this model and the knowledge gained in the previous components of the activities to predict the outcome of physical phenomena related to a real-life problem.

In our modification, the cycles do not always follow the order presented above. For example, after students have explored the electrical properties of a light emitting diode (LED) , they may then explore the spectral properties of this device before they can develop a physical model that will adequately explain their observations. As a result, two exploration activities may be completed by the students before they move to the concept introduction. The order of the cycles are flexible but each unit always begins with an exploration activity.

The instruction units developed for the *Visual Quantum Mechanics* project consist of the following:

- *Solids & Light* (Escalada, Rebello, & Zollman, 1996a),
- *Luminescence: It's Cool Light!* (Escalada, Rebello, & Zollman, 1996b),
- *Potential Energy Diagrams* (Dimitrova, Rebello, & Zollman, 1996),
- *Waves & Wave Functions* (Grabhorn, Rebello, & Zollman, 1996), and
- *Quantum Tunneling: Exploring the Very Small* (Rebello & Zollman, 1996).

See Appendix 1-1 for brief descriptions of each instructional unit.

Each instructional unit consists of sequential activities designed to require about one class period (50 minutes) for the students to complete. The amount of time to complete each unit varies from about one week or 5 instructional hours (*Potential Energy Diagrams*) to two weeks or 10 instructional hours (*Solids & Light* and *Luminescence: It's Cool Light!*) depending on the number of activities contained in each unit.

In addition to the activities, which are available in written form, supplementary resources were developed to make the materials as "user friendly" as possible. For example, the following resources were developed for *Solids & Light*:

- an instructor's manual which provides an overview of the *Visual Quantum Mechanics* project and *Solids & Light*, objectives, student prerequisites, tentative schedule, equipment list, references, trouble-shooting hints and suggestions, open-ended test questions, and information on how to obtain technical assistance (See Appendix 1-2 for a copy of the *Solids & Light Instructor's Manual*); and
- computer programs with user's guides; and
- inexpensive materials (i.e. LEDs) required for one group of students to complete the unit.

Similar type of resources were also made available for the other *VQM* instructional units. The logistic support provided by these supplementary materials is consistent with the recommendation that teachers who try any new curricula require much needed assistance, especially because the individual physics teacher plays the critical role in the success or failure of any new curriculum materials that are being implemented (Arons, 1990).

1.6 The Potential Energy Diagram: A Representation of the Atom

Because quantum mechanics focuses on the microscopic world of atoms and their interactions, any instructional materials on the subject must deal with the issue of representing the atom. Since the atom cannot be easily observed or directly measured, the model of the atom does not need to "look like" the atom

(Golab-Meyer, 1991). The model should be merely a device for predicting the atom's physical properties (Johnston et al., 1996). The *Visual Quantum Mechanics* instructional units utilize the potential energy diagram (or potential well) as the model of the atom because of its ability to explain the properties of atoms of a gas and properties of a solid in terms of energy levels (Escalada, Rebello, & Zollman, 1996a). The potential energy diagram can be used to explain the operation and properties exhibited by most of the modern technological devices such as LEDs, fluorescent lamps, infrared detector cards, and glow-in-the-dark materials that consist of solids.

The atom can be represented by the variation of potential energy of an electron in the vicinity of the nucleus as shown in Figure 1-1. A potential energy diagram that effectively describes the electrical interaction that exists between the positively-charged nucleus and the negatively-charged electron is illustrated in Figure 1-1 and which is a representation of the equation:

$$PE = k\frac{q_1 q_2}{r}$$

where k is a proportionality constant, q_1 and q_2 are the respective magnitudes and signs of the electrical charges of the nucleus and electron, and r is the distance separation between the nucleus and electron.

Unfortunately, this relationship is typically not introduced until the second semester of a physics course when electricity is the topic of discussion. One of the most easily solved problems in quantum physics is that of an electron moving in a force-free region on an x-axis but trapped between two points A and B of Figure 1-2. Figure 1-2, a one-dimensional potential energy diagram (also called a finite, single square-well potential), represents a simplified version of the potential energy diagram illustrated in Figure 1-1. Thus it can be used to represent a simplified atom. This diagram is used through out the *Visual Quantum Mechanics* units as a model for the atom to eliminate the prerequisite that students have any prior knowledge of the equation represented by Figure 1-1 so that the materials could be used in a physics classroom upon the completion of the unit of energy which traditionally takes place in the first semester of the course.

Figure 1-1: ***Example of a Potential Energy Diagram of a Single Atom***

Figure 1-2: ***Simplified Potential Energy Diagram of a Single Atom***

Students are introduced to the concept of potential energy diagrams in the instructional unit, *Potential Energy Diagrams* (Dimitrova, Rebello, & Zollman, 1996). In this unit, students with knowledge of energy conservation can explore a variety of situations involving changes of potential energy in a one dimensional system which consists of a cart, a track, and a series of magnets. By using computer-based data acquisition the students would be able to describe the motion of the cart and its relation to energy-distance graphs. Thus, they would become prepared to use the potential energy diagram as a model for an atom when they move to the other instructional units. Although the one dimensional potential energy diagram is an artificial problem, the model is very good approximation to understanding many complex quantum systems (Morgon & Jakovidis, 1994).

The conventional starting point in analyzing an electron confined to a one-dimensional potential energy diagram is to solve the time-independent Schrödinger equation for a finite square-well potential. This differential equation physically corresponds to an electron being constrained to move in the region between the points A and B of Figure 1-2 by finite repulsive forces. The resulting solutions to this differential equation reveal that an electron bound in the atom will have certain allowable or quantized total energies. These allowed total energies are represented by the dashed, horizontal lines found on the energy diagram illustrated in Figure 1-3.

Figure 1-3: ***Energy Diagram with Three Energy Levels***

The one-dimensional atom represented in Figure 1-3 highlights the important role played by the sizes of various quantum systems in determining the characteristic energy scales of these systems (Morgan & Jakovidis, 1994). Different atoms will be represented by different sizes of potential energy diagrams and as a result will have a different number and values of allowed energies for an electron bound to these atoms. The resulting energy-level model can be applied to describe the quantum structure of nucleons (i.e. protons or neutrons) in nuclei and electrons in atoms, molecules, and solids as well as to explain their physical properties. The energy-level model allows one to expand the concept of energy levels of one atom of a gas to energy bands of many atoms in a crystalline structure. Since LEDs and most luminescent materials consist of solids, this model can be used to explain the operation and properties exhibited by these devices (Escalada et al., 1996a; Escalada et al., 1996b).

1.7 Solids & Light

Solids & Light, introduces students to some basic quantum concepts which can help them explain the spectral and electrical properties of light emitting diodes (Escalada, Rebello, & Zollman, 1996a). The LED is approached from the perspective of energy levels. The unit utilizes a qualitative knowledge of a few concepts discussed in a traditional physics curriculum. The concepts which are used are:

- energy (potential and kinetic) and the law of conservation of energy,
- attraction and repulsion between charges, without explicit statement of Coulomb's Law, and
- graphing the variation of physical quantities.

Concepts which are useful but not required include voltage, resistance, and the relationships between them for a device which obeys Ohm's law and elements of a simple electrical circuit and their role in a simple circuit.

Students begin *Solids & Light* by investigating the current and voltage characteristics of LEDs and compare these characteristics with those of incandescent lamps. Students find that the LEDs are very much different from the classical incandescent lamps. As a result, they begin to study the spectral properties of LEDs and compare these properties with those of gas lamps. After discovering that the spectra emitted by LEDs is more complicated than the spectra emitted by gas lamps, students use computer programs to develop an energy level representation of an atom of gas and apply that representation to atoms of solids to explain the electrical and spectral properties of LEDs. Using these representations, students are able to explain the properties and operation of LEDs without the explicit knowledge of wave functions. Wave functions, however, are discussed in the unit, *Waves & Wave Functions* (Grabhorn, Rebello, & Zollman, 1996).

Solids & Light also contains activities that allow students to apply the concepts learned in the unit to solve real-life, interdisciplinary science problems. The physics concepts are applied to biology and astronomy by allowing students to simulate an investigation on the possibility of life existing on other planets by comparing the spectra of the planets' atmospheric gases with the spectra of known gases.

Another activity allows students to investigate the possibility of using LEDs as a viable light source for plants (Barta et al., 1992). The unit consists of the following sequential activities:

1. *Comparing LEDs to Other Light Sources* (Exploration)
2. *Can Ohm's Law Explain Your Observations?* (Concept Introduction)
3. *Observing Light Patterns Emitted by Light Sources* (Exploration)
4. *Understanding Light Patterns Emitted by Gas Lamps* (Concept Introduction)
5. *Using Light Patterns in Search for Life on Other Planets* (Application)
6. *Using Gas Lamps to Understand LEDs* (Concept Introduction)
7. *Can LEDs Replace Incandescent Lamps?* (Application)
8. *Putting it All Together* (Concept Introduction)
9. *Using LEDs as a Light Source to Grow Plants* (Application)
10. *Using LEDs to Measure Planck's Constant* (Optional)

The LED is a solid state device in which current flows through a solid. As with all solid state devices, the principles of quantum physics are critical in understanding how LEDs work. The LED has unique, observable characteristics which the students can easily measure. For example, LEDs are available that emit various colors of light which can be observed and measured with an inexpensive spectroscope. LEDs also have unique current and voltage characteristics that can be measured when they are connected in a simple circuit apparatus.

Since LEDs are inexpensive, readily available, and adaptable, teachers can utilize these devices in their classrooms with very little difficulty. Using batteries and resistors, LEDs can be connected to simple circuits quite easily. Most physics classrooms have the apparatus (i.e. multimeters and spectroscopes) that can be used to measure the electrical and optical properties of these devices which can lead to an understanding of quantum principles. Since LEDs are cheap and fairly accessible to most everyone, the use of these materials does not convey the attitude that learning physics can only occur through the use of sophisticated and expensive equipment, which may implicitly promote the view that science is only for those who can afford it (Hodson, 1993).

Because of the level of abstraction found in quantum mechanics, the use of concrete real-life devices like LEDs which students see everyday to introduce quantum principles would demonstrate the relevance of physics to their lives. The unique, observable properties of LEDs could also lead to discussions on the contributions of various cultures to science and technology which would increase the relevance of learning physics by students of diversity (Escalada, Baptiste, Rebello, & Zollman, 1997). For example, the hard plastic called resin, which protects the LED from physical damage, could lead to a discussion on how the first plastic (lacquer) was invented in China in the thirteenth century B.C., 3200 years before the Europeans were able to accomplish this feat (Selin, 1993).

1.8 Visual Quantum Mechanics Computer Programs

An essential component to all the *Visual Quantum Mechanics* instructional units are the interactive computer programs. The computer programs utilized in *Solids & Light* consist of the following:

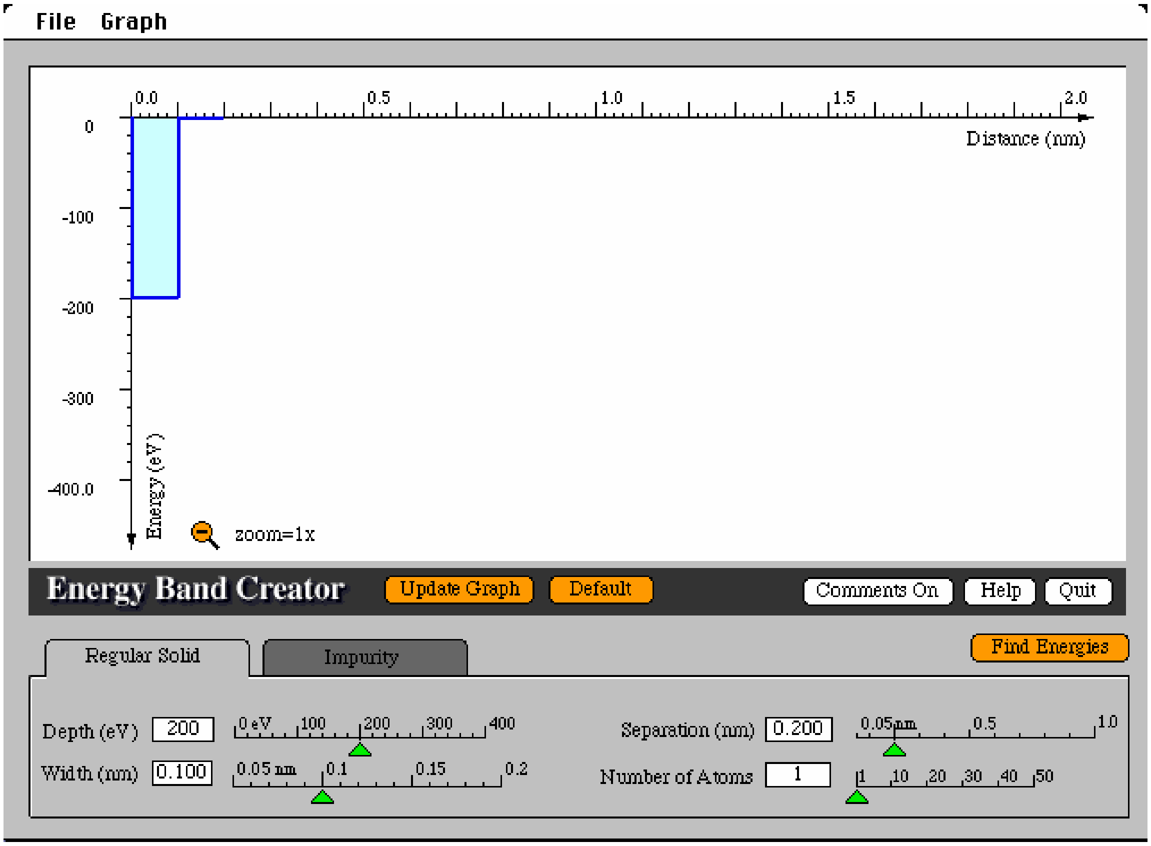
- ***Spectroscopy Lab Suite Software Package*** (described in Donnelly, 1996) contains ***Gas Lamp Spectroscopy*** that allows students to construct energy levels for an atom of a given gas and ***LED Spectroscopy*** that allows students to construct energy bands for the solid materials that makes up an LED when given its respective light spectrum.

- ***Energy Band Creator*** allows students to determine the allowed energy values for an electron bound to an atom(s) represented by a potential energy diagram(s) of any size, and

- ***Semiconductor Device Simulator*** (Rebello et al., 1997) allows students to observe how the LED operates in terms of the concept of energy bands in a solid.

These interactive computer programs perform the mathematical calculations necessary to solve the equations used to determine the energy levels for various quantum systems. (See Figure 1-4.) At the click of a mouse, the students are able to see the resulting allowable total energies for an electron bound to an atom(s) without spending the time and effort to solve formally the necessary equations. As a result, the mathematical formalism that acts as a “filter” in preventing all students, especially female students and students of color, from learning quantum mechanics is eliminated (Escalada, Baptiste, Rebello, & Zollman, 1997). Thus, the focus can now be on developing student conceptual understanding of quantum principles.

Because quantum mechanics focuses on the microscopic perspective of viewing our world, students are not able to observe the inner workings of nature at the atomic level. After students explore the physical properties of LEDs in *Solids & Light*, they use the computer programs to visualize (through the use of computer simulations and animations) nature at the atomic level and to construct an energy-level model that explains their observations and is consistent with quantum principles. (See Figures 1-5 and 1-6). This energy-level model provides the basis to predict the outcome of physical phenomena related to real-life problems. The use of the computer in this manner is consistent with the recommendation of Wells et al. (1995) that computers be used to assist students in creating good models of physical systems.



Depth (eV) 200

Width (nm) 0.100

Separation (nm) 0.200

Number of Atoms 1

Figure 1-4: *Energy Band Creator* Computer Program

The criteria used in the development of these programs were that they be "user friendly" and conducive to an activity-based environment in which students could actively explore and investigate the relationships between the fundamental physics concepts and quantum principles as well as the relationships between the quantum principles and everyday devices. "User friendly" computer programs assure that a higher probability of teachers and students will utilize these materials and technologies in their physics classrooms and that both teachers and students will be comfortable in using it (Escalada, Grabhorn, & Zollman, 1996).

The interactivity of the computer programs allows students to actively engage themselves in their own learning at a pace that is comfortable for them. The computer programs allows teachers to individualize and personalize learning in the classroom, illustrate the relevancy of the subject matter, provide appropriate and immediate feedback, and use analogies to make learning meaningful all of which are consistent with the recommendations found in the *National Science Education Standards*.

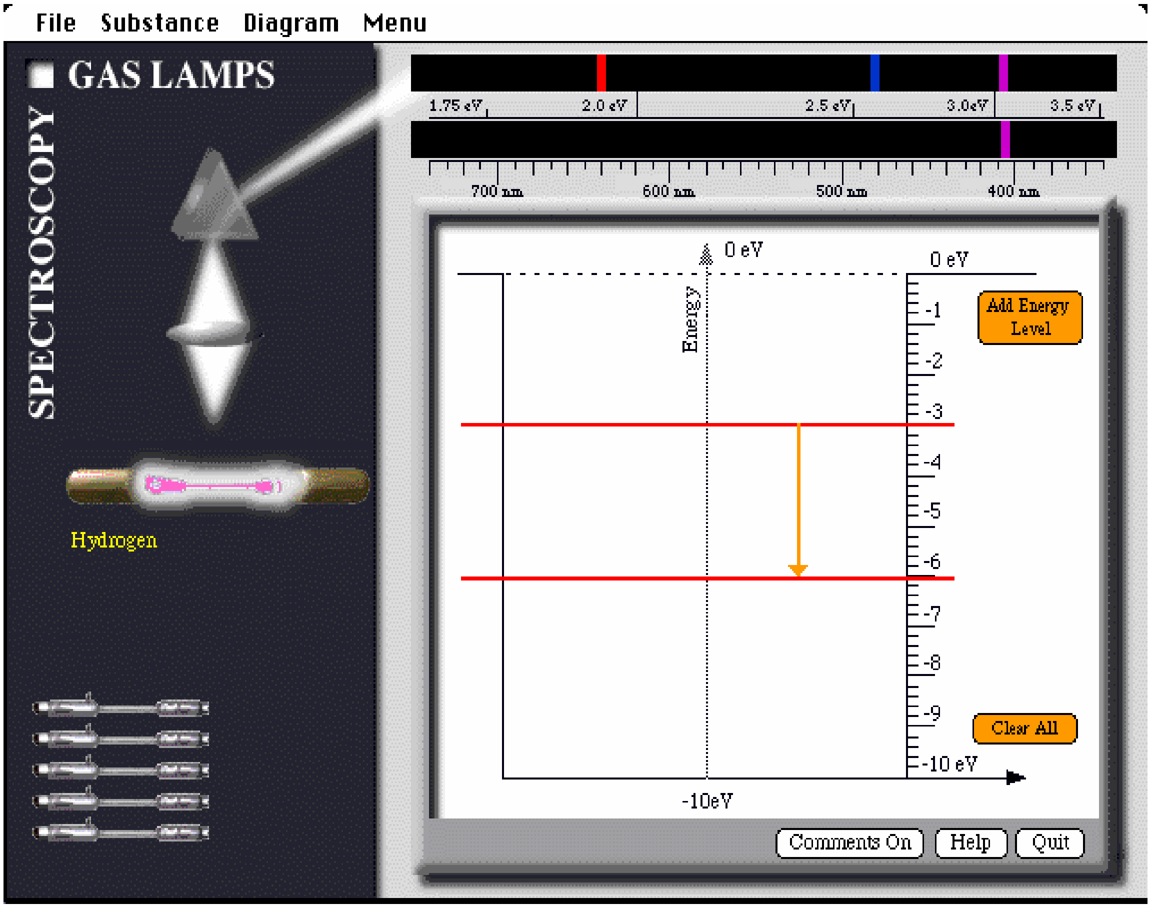
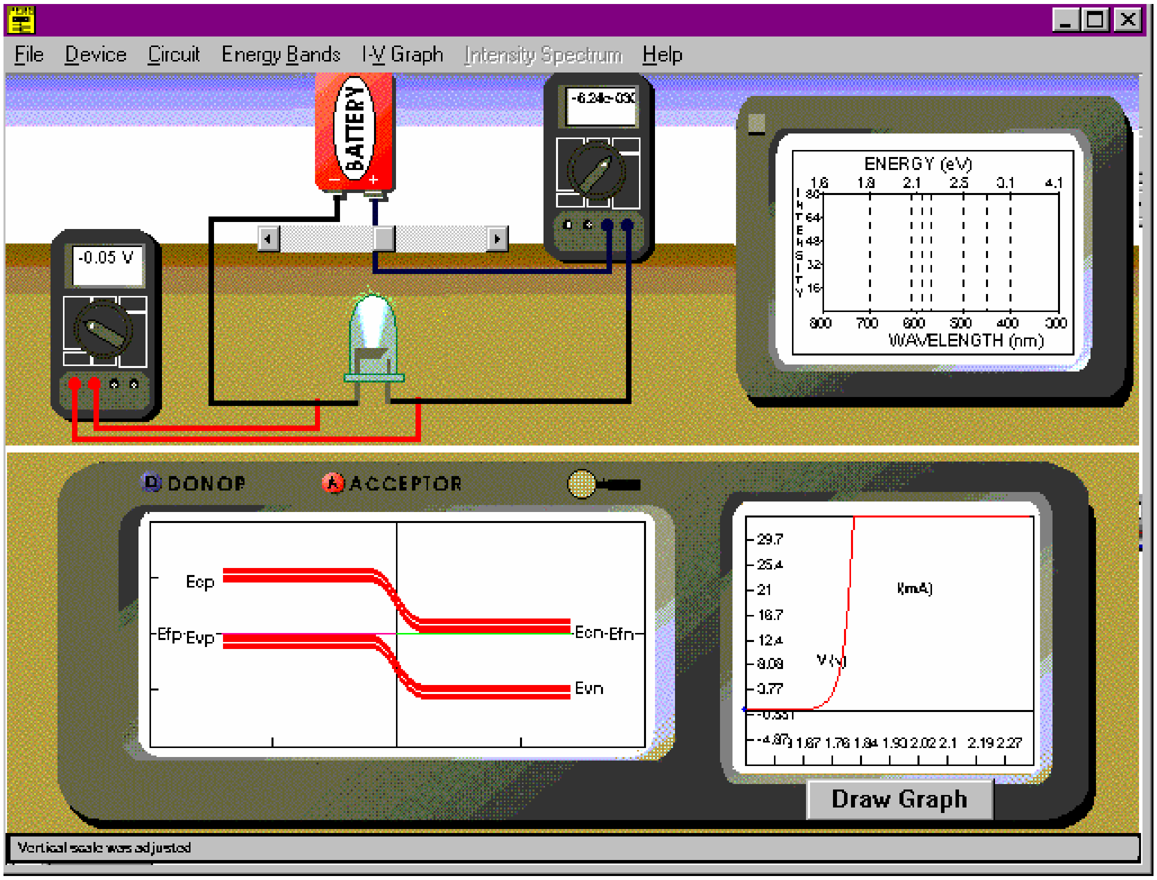


Figure 1-5: ***Gas Lamp Spectroscopy*** **Computer Program**

1.9 Purpose of the Study

Solids & Light has been available for secondary and college physics teachers to field test since March of 1996. This study will investigate the applicability of *Solids & Light* in various high school physics classrooms by examining the effectiveness of the unit and the associated instructional techniques in helping students make observations and develop conceptual understanding of quantum principles. This study will also examine how teachers implement the *Solids & Light* materials in their high school physics classrooms and the student and teacher interactions with the materials and one another by using a non-participant observation protocol. Student and teacher difficulties and misconceptions associated with the use of these materials will also be identified and analyzed. Students' and teachers' attitudes toward these materials will be investigated as well as how these attitudes and student and teacher interactions with the



Vertical scale was adjusted

Figure 1-6: ***Semiconductor Device Simulator*** **Computer Program**

materials are affected by attitudes toward physics and computers, availability of resources, teaching experience and style, gender, and level of physics taught.

CHAPTER 2
REVIEW OF LITERATURE

The objective of *Solids & Light* is to develop students' conceptual understanding of a few quantum principles by using an activity-based learning environment that integrates the use of interactive computer programs and written materials. The design and implementation of *Solids & Light* are based on current science education reform initiatives and research related to developing student conceptual understanding, the learning and teaching of quantum mechanics, activity-based learning environments, and the use of the computer in the physics classroom. The sections that follow describe some of the studies in these areas.

2.1 Physics Education Research

According to Zollman (1995) and Wilson (1994), the most dominant model of teaching high school or college physics is the traditional teacher-centered lecture, laboratory, and recitation format. In this format, students usually take on passive roles and spend a majority of their study time on solving textbook problems. Many studies have concluded that this approach is not adequate for today's learning environment. For example, passive students lack the opportunities to collaborate with their peers or instructors, fail to see the relevance of physics to their own experiences, spend much of the time crammed with too much material, and lack concrete experiences with physical phenomena (Wilson, 1994; Hake, 1992; Van Heuvelen, 1991; McDermott, 1991; Laws, 1991a; Zollman, 1990; Tobias, 1990). According to Tobias (1990), students may become disinterested and drop out of physics altogether as a result of the teacher-centered learning environment failing to develop adequate student conceptual understanding.

Recent national science education initiatives, such as the *National Science Education Standards* (NRC, 1996) and *Project 2061*(AAAS, 1995), and current state science curricular standards (i.e. *Kansas Curricular Standards for Science*, 1995) recommend that to develop student conceptual understanding and scientific literacy a transition from the teacher-centered learning environment to the activity-based, student-centered learning environment must be made. In doing so the attitude that "all students, regardless of gender, cultural or ethnic background, physical or learning disabilities, aspirations, or interest and motivation in science, should have opportunities to increase their existing levels of scientific literacy and to actively learn and develop science knowledge through ‘hands-on’ and ‘minds-on’ experiences enabling them to use their knowledge as it relates to scientific, personal, social, and historical perspectives” is conveyed (NRC, 1996).

By engaging students in learning physics, activities provide students with opportunities to make interpretations which are based on their personal experiences and would allow them to develop conceptual understanding of the topics (Arons, 1990). Arons acknowledges that for a large majority of the students, the conceptual understanding, reasoning, and mastery of basic concepts and ideas will develop only from concrete observational experiences. Laws (1995) agrees by stating that “Activity-based environments combined with interactive discussions and homework are superior to traditional teaching methods for enhancing conceptual development, experimental techniques, and scientific literacy.” .

Redish (1994) defines mental models as the mental framework which individuals construct to organize their experiences related to a particular topic. The particular mental model used by an individual to observe or explain physical phenomena depends not only on the individual’s prior knowledge and experiences (which is the basis of the constructivist epistemology commonly found in current science education initiatives like the *National Science Education Standards*) but also on the context in which phenomena takes place. According to Redish, these mental models can only be developed when students are actively involved in their own learning.

According to some researchers in the field in physics education, many students do not have the appropriate mental models for learning physics and need frequent opportunities to develop and use these models (Wells, Hestenes, & Swackhamer, 1995; Redish, 1994; Van Heuvelen, 1991). These researchers believe that students need access to “touchstone” problems or simplified models that they will understand and use often as the foundation for their complex mental models. These “touchstone” problems enable students to reinforce concrete physics concepts and at the same time develop and internalize more complex, abstract physics concepts.

While developing a student-centered environment, teachers need to take into account the different learning styles and mental models used by different learners (Redish, 1994). According to Laws (1991a), the role of a teacher is to transform oneself from an authority of knowledge to a facilitator who designs creative learning environments in which students can use their knowledge, skills, and experiences as they study physics. The traditional, teacher-centered approach of teaching physics ignores the possibility that the perception of students may be very different from that of the instructor (McDermott, 1993). This conclusion may be especially true for female and/or culturally diverse students whose experiences and views may be different than the experiences of and views held by their physics instructor who traditionally has been white and male. According to a 1989-1990 nationwide survey of high physics teachers, less than 20% of the teachers were females and less than 4% were from cultural diverse backgrounds (Neuschatz & Alpert, 1994). By not acknowledging and addressing these different experiences and views, the instructor is not taking advantage of opportunities to make learning physics personally relevant and important for each individual student.

As the physics teacher assumes the role of a facilitator, engaging student interest becomes an issue. McDermott (1993) stresses the importance of qualitative questions that require explanations of reasoning to engage student interest, focus attention on key issues, encourage reflection, and assess student conceptual understanding. An example of the importance of qualitative questioning in assessing student conceptual understanding is a story told by Arons (1990) in which he asked graduate students in a qualifying exam to explain qualitatively how the quantum model of the atom accounts for the difference between the absorption and emission spectra of sodium:

> "Of the 14 students who took the exam, only one of the 14 gave the correct response that, in absorption, electrons are elevated from the ground state to higher states and would see those transitions, while in emission, electrons cascade down through intermediate states, in addition to dropping directly to the ground state, and thus produce additional lines. Five students attempted to use quantum mechanical equations with selection rules and reached no conclusion. The remaining students left the question blank."

Arons concludes that these students were not incompetent but simply had never been asked to answer basic qualitative questions. This example illustrates the need to expose physics students at all levels to such qualitative questions from their earliest encounter with a topic.

In any physics curriculum students' common difficulties and misconceptions need to be explicitly addressed (McDermott, 1993; Hake, 1992; Van Heuvelen, 1991). To address student misconceptions or prior conceptions, instructional strategies must be used that will generate conceptual conflicts and require the students to resolve it (Redish, 1994; Driver et al., 1994; McDermott, 1993; Minstrell, 1992). In order for a student to replace an existing conception with a new one, the student must encounter in some dissatisfaction in using the existing conception, and a new intelligible and initially plausible conception must be available that resolves these difficulties (Posner, Strike, Hewson, & Gertzog, 1982). If the new conception not only resolves its predecessor's difficulties but also leads to new insights and discoveries, then the conception will have the potential to replace completely the prior conception and to be extended to other areas. For student misconceptions to be addressed and significant conceptual change to occur, active learning must be an essential component in any secondary physics curriculum (McDermott, 1993).

2.2 Teaching Quantum Mechanics

The Newtonian perspective of the world is so much a part of the physics culture that it infects the teaching of modern physics topics as well (Hobson, 1996; Barad, 1995). In learning classical physics students develop visualizable, qualitative mechanical models to understand abstract concepts used to explain physical phenomena (Brown, 1992). This knowledge of classical physics with its use of mechanical models and concepts contributes to the difficulty of learning quantum mechanics (Fischler & Lichtfeld, 1991). Fischler & Lichtfeld recommend simplified models be constructed in such a way that they can be extended to complex cases so that the student is not forced to reorientate his or her basic conceptions. This process especially applies to visual and qualitative models used to explain physical phenomena which are very attractive to students because of their familiarity with these models in their everyday life. According to Fischler & Lichtfeldt the more these models are strengthened in class the more difficult it is to replace them. They recommend that if students are to develop conceptual understanding of quantum mechanics, these models must be replaced.

One such mechanical model that contributes to the difficulty of learning quantum mechanics is the Bohr model of the atom (Fischler & Lichtfeldt, 1992). Bohr's planetary model of the hydrogen atom provides introductory physics students an unique opportunity to integrate in one context a large volume of fundamental concepts that include circular motion, centripetal force, Coulomb's law, kinetic and potential energies, absorption and emission of light, conservation of energy, bright line spectra, electrons, the nuclear model of the atom, and the photon concept (Arons, 1990). Bohr's theory of the atom, however, because of its quantum discontinuities combined with its classical orbits is not an adequate mode of description in a quantum physics model of the atom (Hobson, 1996; Fischler & Lichtfeld, 1992; Niedderer et al., 1990). Fischler & Lichtfeld recommend that Bohr's model should be avoided also because of the difficulty of students in abandoning this illustrative model of the atom for the sake of a better model that explains the interactions of atoms. Further, prior to any instruction some students already possess a fixed idea of an electron in an atom being strongly based on this mechanical model. Many students have learned the mechanical but not the quantum component of Bohr's model (Unal, 1996). This pre-conception of the atom has been shown to affect students learning of quantum mechanics (Fischler & Lichtfeld, 1992; Niedderer et al., 1990).

The quantum representation of the atom based on the Schrödinger equation, on the other hand, allows for more and better physical explanations than the Bohr model of the atom, especially with regard to complex atoms, molecules and solids, and meets the ideas of modern scientists (Petri & Niedderer, 1995; Morgan & Jakovidis, 1994). Unfortunately, secondary science textbooks often do not emphasize the limitations of the Bohr's model and as a result do not provide a sufficient basis for students to rationally accept the quantum model over the Bohr model (Shiland, 1997).

In thinking about quantum mechanics, students must move beyond models based on direct observations and towards models that incorporate abstract properties (Johnston et al., 1996). In the past, students utilized mental models that were very visual and illustrative. They learned to create images or draw pictures to help conceptualize various ideas. The model used in quantum mechanics requires a further level of abstraction.

Because of this level of abstraction, the teaching of quantum mechanics traditionally requires the development of a substantial number of new concepts or terms (Reimann, 1986). The terminology can easily overwhelm the ordinary student and get in the way of developing student understanding. A good model or analogy can eliminate the need for introducing excess vocabulary by providing a "concrete" basis for easy visualization of many physical properties exhibited by quantum devices.

One such model of the quantum atom is the energy-level model. Unlike most visual mechanical models, the energy-level model describes the atom's physical behavior but not its physical properties. A energy-level description used to represent the atom cannot be considered to "look like" the atom. It is merely a device for predicting the object's physical properties (Johnston et al., 1996). According to Johnston and his colleagues, bringing students' thinking to this level of sophistication is one of the most difficult aspects of teaching quantum physics.

Niedderer and his colleagues (1990) found that German high school students in a variety of situations can use different conceptions (modern and classical) to explain energy levels. They also found that these students were easily able to connect the concept of quantum state with the idea of energy levels. The quantization of energy was readily accepted by students, and they did not ask for a physical explanation of this fact. Students didn't seem to "need" a more sophisticated atomic model. The importance of these findings is that an abstract quantum model based on energy levels can be understood by students.

Niedderer and his colleagues also found that students use the concept of energy actively in their own reasoning. The conservation of energy plays an especially important role in students' own explanations especially as it is related to the emission and absorption of light in atoms or molecules.

In teaching quantum mechanics Fischler & Lichtfeldt (1992) recommend the use of probabilistic interpretation and the avoidance of dualistic descriptions to explain observed phenomena. They recommend that quantum mechanics should include such topics as electron diffraction, quantization of energy for a square-well potential and for a hydrogen atom, the Frank-Hertz experiment, and spectroscopic analysis. Consistent with this spectroscopic approach, Hood (1993) suggests that the results of quantum theory at the introductory level should include the hydrogen atom energy level scheme and the emission and absorption of photons in atomic hydrogen.

According to Strnad (1981) the traditional approach of teaching quantum mechanics based on the concept of matter waves and on the naive photon concept needs to be modified. Strnad recommends a new approach called *Quantum Physics for Beginners*. The topics in this new approach include: the failure of classical mechanics; energy of helium atom and other atoms; line spectra; Planck's constant; states of the hydrogen atom; energy levels of electrons in atoms; energy bands in crystals; insulators, semiconductors, and conductors; semiconductor diodes and transistors; lasers; and photons.

Recently, Hobson (1996) described a liberal-arts physics course for non-scientists at the University of Arkansas that devotes 50% of the lectures to modern physics while still including classical topics such as

Newtonian mechanics, gravity, thermodynamics, and electromagnetic radiation. The course like most non-science physics courses focuses on conceptual understanding rather mathematical calculations. Hobson begins the course by providing the motivation for learning quantum theory which is the main modern physics topic. The course then continues with a description of the photoelectric effect and the ideas of Planck and Einstein that lead up to the Particle Theory of Radiation. Students then perform experiments that are consistent with the particle theory of radiation and experiments that are consistent only with a wave theory of radiation. By applying the double-slit experiment to electrons, students find that matter and radiation both have a dual wave/particle nature. A discussion of de Broglie's prediction of wave effects of matter follows these experiments. The students are then introduced to the basics of quantum theory including uncertainties, matter waves, probabilistic interpretation, and the idea of Schrödinger equation without the emphasis on mathematics. According to Hobson, the quantum atom makes these quantum theory basics concrete. He cautions, however, that quantum theory is much more than atoms, and it is misleading to make the atom the focus of quantum theory.

Hobson recommends that teaching quantum theory should begin with a study of the line spectra of diffuse gases. A discussion on how they can be explained in terms of Bohr's model of the atom and why only certain wavelengths are emitted would then take place. The discussion would then focus on the problem with Bohr's model that when coupled with classical electromagnetic theory would erroneously predict that an orbiting electron would eventually spiral into the nucleus. The focus would then shift to how the quantum theory represents the "orbiting" electron in terms of quantum states. The course would continue with a discussion on atomic transitions as well as other examples of quantum jumps and its association with detection events. Hobson makes the point that microscopic experiments are critically dependent on the entire experimental arrangement, especially the placement of detectors. The behavior of microscopic entities such as electrons is intimately bound up with such macroscopic entities as slits and fluorescent screens (Hobson, 1996).

The quantum topics suggested by Hobson (1996), Hood (1993), Fischler & Lichtfeld (1992), and Strnad (1981) would require at least a semester to cover. Arons (1990) cautions that one-semester courses which attempt to give insight into topics such as quantum mechanics will fail because they subject students to an endless amount of terminology that is outside the learner's realm of experience and because the subject matter is covered too quickly and in far too great a volume for significant conceptual understanding to occur. Arons also warns that students should not be told about the "fascinating" particles of high-energy physics with incomprehensible jargon about interactions, mass-energy relations, and quantum transitions when they have inadequate understanding of such basic concepts as velocity, acceleration, force, mass, energy, and electrical charge.

The use of excessive jargon can add to the level of abstraction that is associated with learning physics. Although accurately understood science terms should become part of the permanent vocabulary of scientifically literate individuals, the excessive use of technical terms as evidence of understanding should be discouraged (AAA, 1993). In communicating about science, the presence or absence of vocabulary does not necessarily reflect students' levels of understanding (Lee, Fradd, & Sutman, 1995). For students of cultural diversity whose first language may not be English, the terminology of science and, more particularly, the specialized usage that science makes of familiar words (i.e. energy, force, work, etc.), together with technical terms can create a major problem for learning to take place (Hodson, 1993). Too early an insistence on precise terminology and formal writing style can be frustrating for those with limited linguistic skills. The focus on terminology and formal writing style can also lead to student withdrawal or even alienation from science.

2.3 Learning Cycle and Active Learning

In the field of science education the learning cycle has been in existence as an instructional model for several decades (Lawson, Abraham, & Reuner, 1989). The learning cycle was developed as part of the *Science Curriculum Improvement Study* program in the 1960s (Karplus, 1977; Karplus & Thier, 1967; Atkins, 1962). Based on Piagetian theory, it has traditionally been described as a model of instruction that focuses on an exploratory investigation preceding any formal introduction to scientific concepts.

Since its introduction in the 1960s, the learning cycle has had many variations on the traditional exploration-concept introduction-concept application design as developed by Karplus and his colleagues and has become incorporated in a variety of science curricula and programs (Tobin et al., 1994). For example, a new approach to teach introductory physics called the modeling cycle, which is a refined version of the learning cycle, has been developed by Wells, Hestenes, & Swackhamer (1995). The modeling cycle engages students to develop and use scientific models with the aid of basic conceptual tools such as graphical, mathematical, and graphical representations to describe, explain, predict, and control physical phenomena.

The learning cycle has also been adapted to a large-enrollment, introductory physics course for elementary majors (Zollman, 1990). The course provides experiences in physics which are appropriate to future elementary teachers and which provide a model for appropriate ways to teach science in any classroom. The instructional method utilizes an open laboratory environment for "hands-on" exploration and application activities as well as a discussion format for the introduction of new concepts. The discussion component of the course is used to illustrate the relationships among the various activities of the exploration and help students understand a model or theory that explains their observations during the exploration. The central feature of the course is the activities that students perform. The learning cycle allows the focus to be on the activities and concentrates the students' attention on the importance of these activities as methods of teaching science. Students frequently report on course evaluations that they succeeded in learning physics only because they completed the activities. This attitude reflects the importance of an activity-based environment on student learning.

The learning cycle has also been adapted to curriculum materials designed for high school physics students. One example is the *Physics Resources and Instructional Strategies for Motivating Students* (*PRISMS*) materials (Unruh & Cooney, 1997; IPTF, 1993; Unruh, Countryman, & Conney, 1992). The *PRISMS* materials are hands-on, inquiry-based activities that utilize the learning cycle as developed by Karplus (1977). Over 130 activities utilize easily obtainable, inexpensive materials (i.e. Hot Wheels™, toy projectiles, model sailboats, skateboards, plastic straws) and encompass an entire year of high school instruction. Unruh and his colleagues found that by using these materials, students:

- depend less on instructions how to complete an laboratory or activity,
- had a more positive attitude toward learning physics,
- related physics more to their everyday experiences,
- demonstrated a higher degree of independent thinking, and

- asked more questions than were generated by their laboratory activities.

Teachers also observed that the quality of student-teacher and student-student interactions while completing labs or activities were significantly enhanced. The *PRISMS* program has been validated by the *National Diffusion Network* which was a U.S. Department of Education sponsored clearinghouse of model educational programs. Validation was based on convincing evidence that the program was causing significant and positive changes in a group that it was intended to affect. The validation study, conducted with 45 *PRISMS* schools and 30 control schools during the 1985-1986 academic year, evaluated the program in terms of physics content achievement with the *New York Regents Physics Examination*, the development of reasoning and science problem-solving skills using the *Test of Integrated Process Skills* (Burns, Okey, & Wise, 1985; Dillashaw & Okey, 1980), and attitudes toward learning physics with the *Physics Attitude Index* (Gardner, 1976).

Because the learning cycle is conducive to an activity-based environment, the approach has also been used in laboratory activities in addition to the specific physics courses and curricula mentioned previously. Renner and Abraham (1985) found that students believe learning physics is enhanced by utilizing a learning cycle that focuses on laboratory activities. Their study found that students believe the use of a learning cycle facilitates learning, and they like it best. Renner and Abraham attributed increased enrollments to the use of the learning cycle.

Although the use of the learning cycle can facilitate active learning and positive attitudes toward learning physics, Siraj-Blathford (1987) cautions that the use of the discovery learning method similar to exploration phase of the learning cycle may cause students who do not discover the “correct” result to account for their “failure” in terms of ethnicity, gender, or social class. In using the learning cycle, teachers must convey to their students that the results of an exploration phase of the learning cycle does not have a correct or wrong answer. Conveying this attitude to students is essential so that students do not attribute their results to being a failure. As a facilitator of an activity-based learning environment, the instructor’s responsibility is not to direct the student to a “correct” answer but to guide a students conceptual development based on the context of their observations.

Obviously, the learning cycle focuses on a student-centered, activity-based learning environment. The learning cycle is consistent with the "active" process of learning science as described by the *National Science Education Standards* (NRC, 1996) which calls for physical ("hands-on") and mental ("minds-on") activities. "Hands-on" and "minds-on" activities, as defined by the *Standards*, are "inquiry-oriented investigations in which students interact with teachers and peers; establish connections between their current knowledge of science and the scientific knowledge found in many sources; apply science content to new problems; engage in problem solving, planning, decision making, group discussions; and experience assessment that are consistent with the active approach to learning" (NRC, 1996).

In addition to increasing student conceptual understanding and motivation, hands-on activities can improve attitudes towards learning and reduce anxiety associated with learning (Chamot & Arambul, 1985). Research also has shown that students with a language barriers become more proficient in an environment with hands-on and minds-on activities (Mason & Barba, 1992). Hands-on activities provide students who have language barriers with opportunities to structure their primary language around these "touchstone" situations.

Female students, students of color, and students with language barriers are often underrepresented in physics courses and in science courses in general (Weiss, 1994; Rakow & Bermudez, 1993; AAUW, 1992; Oakes, 1990; Atwater, 1986). A number of educators and researchers (Allen-Sommerville, 1996; Baptiste & Key, 1996; Baker & Leary, 1995; Anderson, 1994; Rakow & Bermudez, 1993) suggest that increasing the enrollment and the achievement of these groups of students in science courses can be addressed by actively engaging them in hands-on experiences in the science classroom. They also suggest that the following techniques be used to address the problem:

- introduce the relevancy of the subject matter,
- individualize and personalize instruction,
- use multiple instructional strategies,
- use meaningful analogies,
- provide immediate and appropriate feedback,
- illustrate the diverse history of science, and

- assume all students can learn.

Most of these suggestions are similar to the recommendations made in the *National Science Education Standards* and by the American Association of Physics Teachers to improve the scientific literacy and conceptual understanding for all students. These instructional strategies are especially effective for those students who have not traditionally enrolled in or been successful in traditional high school physics courses. Using these strategies to eliminate the attitude that physics is only for those who are extremely intelligent and capable would be a step in the right direction in increasing the scientific and technological literacy of all students and not just a select few (Escalada, Baptiste, Rebello, & Zollman, 1997).

In addition to effectively developing conceptual understanding by engaging students in the active process of learning physics, many physics education researchers suggest that the use of concrete real-life experiences and analogies can also be effective (Zollman, 1994; Redish, 1994; McDermott, 1991; Van Heuvelen, 1991; Arons, 1990). Showing the connection between physics and real-life experiences helps students perceive the relevance of physics to their own world (Escalada & Zollman, 1997; Escalada, Grabhorn, & Zollman, 1996; Zollman, 1994a). Showing the connection between science and real-life experiences can be especially effective to develop conceptual understanding for students of cultural diversity especially when real-life examples, analogies, and contexts that are culturally relevant are utilized (Escalada, Baptiste, Rebello, & Zollman, 1997; Barba, 1993; Rakow & Bermudez, 1993). McDermott (1993) and Laws (1991b) maintain that students need frequent opportunities in making connections between abstract concepts, formal representations, and real-world, everyday phenomena.

The nature of a classroom learning environment, whether it is based on the active process or the passive process of learning science, is strongly dependent on the curriculum materials such as laboratory manuals, worksheets, and texts (Lazarowitz & Tamir, 1995). Worksheets are usually prepared by the teacher and as a result allow flexibility and correspondence with students' capabilities. However, teachers often do not have the knowledge or time and resources available to be authors of texts and laboratory manuals. As a result the quality of teacher-designed exercises in these materials leaves much to be desired (Lazarowitz & Tamir, 1995; Arons, 1990). The development of inquiry-oriented activities is especially demanding because of the need to try the investigations and to assure that they "work", as well as the importance of having "balanced" exercises in terms of their "cognitive challenge" (Gardner & Gauld, 1990). Because of these difficulties, teachers rarely invent activities; instead, they adopt them from various sources.

Although the nature of the classroom transactions is strongly dependent on the curriculum materials, they will never achieve the goal of a student-centered learning environment entirely by themselves (Arons, 1990). The teacher also plays a crucial role. A teacher can negate the intent of the curriculum materials by attitude, expectations, and most significantly, by how he or she assesses student understanding. The teacher must be secure in the use of the curriculum materials in order for the successful implementation of these materials in the classroom to occur. "Security" in this context means both thorough understanding of the subject matter and of the underlying pedagogical intent and design of the materials (Arons, 1990).

Arons recommends that teachers who try any new curricula need logistic support. Hands-on, activity-based materials require continual maintenance and resupply. Busy and overworked teachers need sustained support in using such materials. They cannot take care of the logistics in addition to their regular duties.

Positive attitudes toward a phenomenon, object, or event are prior conditions to behavior changes (Lazarowitz & Tamir, 1995). Therefore, serious consideration must be given to providing physics teachers with an investigative experience so that they will have positive attitudes toward a new approach to teaching physics. Teachers must be guided slowly and carefully through the same intellectual experiences they wish to convey in their own classroom (Arons, 1990).

Curriculum materials must give students opportunities to be responsible for their own learning and to demonstrate a deep robust understanding of fundamental physics concepts rather than the mastery of many seemingly insignificant, isolated facts (Clough & Clark, 1994). Although the curriculum materials may be directed toward this type of student-centered learning environment, the individual teacher determines how the material and related concepts will be presented. In a student-centered environment essential teacher behaviors should include questions with extended answers, questions that require students to elaborate on their ideas, providing sufficient time for students to answer questions, non-judgmental responding behaviors, encouragement, observation, and listening. All of these factors are important in developing students' conceptual understanding of physics. The curriculum materials can be as activity-based and student-centered as possible, but if the teacher does not exhibit these behaviors, the materials will not work as intended. Ultimately, the teacher determines if the curriculum materials will be successful or not (Arons, 1990).

2.4 Use of Computers in an Introductory Physics Course

The *National Science Education Standards* recommend that students need to have easy and frequent access to a wide range of equipment including computers and computer applications, materials, and other resources for facilitating the active process of learning science (NRC, 1996). High school science teachers also believe that the use of computers is an effective tool in helping students be actively involved in learning science (Weiss, 1994).

Computers in the physics classroom can provide quick and easy access to various forms of information. For example, the *Physics InfoMall* is an extensive CD-ROM database designed to supplement the references available to high school and college physics faculty and students (Fuller & Zollman, 1995). The *InfoMall* provides the user access to 35,000 pages of materials from textbooks, journal articles, demonstrations, laboratory manuals, activities, and other documents. With relative ease, the user can browse through these documents, search any or all of the documents on the CD-ROM database, mark any interesting information for future references, and extract text and graphics to a word processor or printer.

Computers can introduce and reinforce concepts by various forms of drill, practice and tutorial work. Computers can allow students to be actively engaged in and have control of investigations of physical phenomena. For example, computers can be interfaced with computer-based laboratory tools or have interactive digital video capabilities. The laboratory tools allow students to collect analog data of physical phenomena, to convert that data to digital input, and then to transform that data into graphs that are displayed on a computer screen at the same time data is being collected (Nakhleh, 1994).

Interactive digital video allows students to capture video of physical phenomena unto the hard drive of the computer (Escalada & Zollman, 1997; Escalada, Grabhorn, & Zollman, 1996). A variety of visualization techniques have been developed to play back and analyze the motion of the objects captured in the video (Escalada, Grabhorn, & Zollman, 1996; Beichner, 1996; Laws & Cooney, 1996; Patterson, 1996; Wilson & Redish, 1992).

Computers can also allow students to visualize and/or simulate physical phenomena and abstract concepts in the form of computer simulations, animations, models, real-time graphs, and video. Computer simulations and/or animations can provide viewpoints on phenomena that are difficult or impossible to achieve in classroom demonstrations. Students can even experience simulations of events that would be physically impossible, allowing them to compare the implications of their own beliefs about the world to those of modern scientific theories (Lesgold & Reif, 1983). They can simulate microscopic events that can occur inside a molecule or macroscopic events that involve an entire galaxy. Most important of all, simulated phenomena can be presented in way that allows students to focus on centrally important events without being distracted by logistic details.

Computer programs can eliminate the requirement of mathematical proficiency by performing all the necessary calculations. This approach can change or eliminate the focus of such topics as quantum mechanics from manipulation with abstract mathematics to conceptual understanding of the solutions to equations. Niedderer, Bethge, Cassens, and Petri (1996) have been working on such a computer tool to model Schrödinger's equation for different applications. Their approach uses analogies from standing waves in one, two, or three dimensions to familiarize students with the quantum concepts of "state" and "orbital". This qualitative approach avoids overwhelming the student with mathematical formalism and helps focus their attention on interesting phenomena such as complex atoms with more electrons, molecules, and solids. The focus is to apply this quantum model to a wide range of phenomena in atomic physics, chemistry, and solid-state physics.

These treatments frequently include visualization or animation techniques. The use of computer animations in the classroom may increase student conceptual understanding. Williamson and Abraham (1995) found that treatment with computer animations may increase conceptual understanding of chemistry concepts by prompting the formation of dynamic mental models of the phenomena. They believe the dynamic quality of animations may promote deeper encoding of information than that of static visuals such as transparencies or chalk diagrams.

The use of the computer has the potential to enhance student learning in physics, especially modern physics (McDermott, 1993). However, McDermott warns that many computer programs are not matched to the needs or abilities of students. The computer can enhance student conceptual understanding of physics concepts only when the software is designed with the specific student needs, abilities, and difficulties in mind (Grayson, 1990).

When it comes to the use of computer simulations in the physics classroom, Arons (1984) advises that if the physical phenomena is readily accessible to students, then introductory students should be exposed to the actual phenomena rather than to the computer simulations. Lazarowitz & Tamir (1995) suggest that students benefit from computer simulations after they had some experience with the real phenomena. They warn that continuous learning with computers might cultivate dependence on the reinforcement provided by the computer so that students would not be able to engage in genuine independent learning, ask their own questions, or check their own reasoning for internal consistency.

Used appropriately computers can facilitate the use of the instructional strategies recommended by the *National Science Education Standards* (NRC, 1996) to develop student conceptual understanding of science concepts. McDermott (1991) cautions, however, that even a highly interactive computer program provides no guarantee that students will be engaged at a sufficiently deep level for significant concept development to occur. The common pitfall of abandoning students to the isolation of individualized computers must be avoided at all costs. The computer itself does not necessarily promote inquiry learning; it is the interaction of the students with one another, the teacher, the materials, and the computer that constitutes inquiry learning.

In using equipment such as computers in the classroom, teachers must be careful not to promote the view that physics can only be learned through the use of expensive and sophisticated equipment (Hodson, 1993). The dire consequence of this view is that physics will be eliminated from students' everyday experiences.

As was the case for curriculum materials, the use of computers in activity-based science classrooms can offer the potential to facilitate students' conceptual understanding. The teacher, however, continues to perform a central role in mediating the quality of student learning (Maor & Taylor, 1995). Maor

& Taylor found that teachers who promote the active construction of knowledge of their students are more likely to enable students to better exploit the potential of the computer for developing conceptual understanding as opposed to teachers who control too closely students' interactions with computerized instructional programs and provide too few opportunities for students to explore issues that are of compelling interest to them. The computer itself does not necessarily promote inquiry learning; the teacher and the students collaborative grasp of the tool constitutes inquiry.

2.5 Summary

The reports and previous studies reviewed in this chapter reveal a broad range of topics that are directly or indirectly related to the present study of determining the applicability of *Solids & Light* and the associated instructional strategies in various high school physics classroom environments. Although the literature that specifically examines the qualitative approach of teaching quantum physics to introductory physics students with limited mathematical and physics backgrounds is relatively scarce due to the uniqueness of this approach, the literature cited does support the merits of this approach as well as common pitfalls that lead to student/teacher misconceptions and difficulties to avoid. Hence, the majority of the reports and studies covered in this chapter focus on certain important aspects of the present study.

CHAPTER 3
METHODOLOGY

3.1 Development and Evaluation

The development and implementation of *Solids & Light* was based on the reports and studies reviewed in the last chapter. This development has also relied on feedback from teachers who implemented similar type of materials in their physics classroom and the revisions of the unit were based on constant feedback provided by both teachers and students who field tested earlier versions of these materials.

The *Visual Quantum Mechanics* (*VQM*) project began in February of 1995. The pedagogical strategy for *Solids & Light* was based on the activity-based instructional approach of the learning cycle (Zollman, 1990) in which an exploratory investigation of concrete, quantum-related phenomena (i.e. electrical and spectral properties of LEDs) preceded any formal introduction of abstract, quantum principles (i.e. discrete energy states, energy gaps, and energy bands). This approach was consistent with the recommendations made in current science education initiatives and found in studies and reports of Zollman (1995), Lazarowitz and Tamir (1995), Weiss (1994), Laws (1991a), and Arons (1984). The research conducted by Johnston et al. (1996), Fischler (1996), Niedderer et al. (1996), Petri & Niedderer (1995), Fischler & Lichtfeldt (1992), and Niedderer et al. (1990) provided important guidelines on how the quantum principles should be introduced. In addition, the use of physics terminology that did not contribute to the development of quantum principles was avoided in *Solids & Light* which is consistent with the recommendations made by the American Association for the Advancement of Science (1993), Hodson (1993), and Arons (1990).

The physics topics and phenomena introduced in *Solids & Light* and their sequence was also consistent with various reports and studies of Hobson (1996), Morgan and Jakovidis (1994), Hood (1993), and Strnad (1981) as well as the *New York Regents High School Physics Curriculum* (Moreau, 1991), which includes topics on modern and solid-state physics. In addition, simple hands-on activities that allowed for student manipulation and observation of the physical properties of LEDs along with interdisciplinary applications of LEDs were located from various articles and materials of Lottis and Jaeger (1996), Ellis et al.

(1993), Waltner and Lehman (1993), Bula et al. (1991), Jewett (1991), Sievers and Wilson (1989), and O'Connor and O'Connor (1974).

As part of the development process, in the Fall of 1995 an advisory committee consisting of physics faculty from a number of high schools and universities around the country reviewed the goals and direction of the project, the proposed content of the instructional units, and the pedagogical design of the instructional materials. The advisory committee provided valuable feedback on pedagogical issues that arose during the development of the *Solids & Light*. For example, the committee addressed how students should connect the components of an electrical circuit. The issue focused on whether a device in a form of a "blackbox" (an apparatus that is already constructed for the student to investigate physical phenomena without revealing how the circuit was constructed) or a breadboard (a device used to connect delicate electrical components which allows students to investigate phenomena and to study how the apparatus was constructed) should be used. From these discussions on the pedagogical design of an electrical apparatus, a recommendation was made that the materials should provide teachers with as many options as possible to address the issue of the accessibility of equipment and resources for a high school physics teacher (Neuschatz & Alpert, 1994; Weiss, 1994; Baird et al., 1994). Several prototypes of these electrical circuits were developed as a result of these discussions. The recommended circuit apparatus for the first activity of *Solids & Light* is illustrated on page 45 of the *Solids & Light Instructor's Manual* found in Appendix 1-2.

The advisory committee also made suggestions and recommendations on the type of instructional support that should be provided to a physics teacher who would implement the *Solids & Light* materials in his or her physics classroom. Logistic instructional support is consistent with the recommendation that teachers who try any new curricula require much needed assistance, especially since the individual physics teacher determines the success or failure of any new curriculum materials that are being implemented (Clough & Clark, 1994; Arons, 1990). In addition to the written *Solids & Light* activities, LEDs, and computer programs, teacher-oriented supplementary resources were provided as discussed in Chapter 1.

Pedagogical issues like the ones previously mentioned reflect the importance of the next phases of the *Visual Quantum Mechanics* project which include extensive field testing and the formative evaluation during which the project is assessed and feedback is collected. These phases are essential for the successful development of students conceptual understanding of quantum mechanics and its applications as well as for the successful implementation of the *VQM* instructional units in the introductory physics curriculum at the secondary and university levels.

Solids & Light underwent extensive revisions based on preliminary testing of these materials by a group of elementary education majors enrolled in an introductory physics college course in the Fall of 1995 and a group of secondary science education majors enrolled in a contemporary physics course in the Spring of 1996 at Kansas State University. The elementary education majors who were enrolled had not studied any concepts related to quantum physics or even concepts related to wave motion or light when they completed these activities. Because 90% of these students had no formal course in physics since middle school, they represented the intended audience of the *VQM* materials. Initial results revealed that these students felt comfortable interacting with the quantum principles being introduced, the materials, and the computer programs within the context of the activity-based learning environment. This initial field test also revealed some misconceptions held by the students regarding some quantum principles. As a result of this field test, the curriculum materials were modified and new interactive computer programs were created to address these misconceptions. For example, after students were introduced to the concept of allowed energy levels for an electron in an atom, the common misconception was that each energy level corresponded to a different color of light emitted by an electron bound to an atom, rather than to the difference between two energy levels. The interactive computer program, *Gas Lamp Spectroscopy*, was developed to address this misconception. The program allows students to construct the energy levels for an atom of a given gas when given its atomic spectra and to visualize the relationship between the resulting spectra and the electronic transitions. This computer program led to the development of *Spectroscopy Lab Suite Software Package* (Escalada et al., 1996ab; described in Donnelly, 1996) which contains computer programs that allow students to construct energy levels for an LED, a fluorescent tube, an infrared detector card, and a phosphorescent toothbrush and to observe the relationship between energy levels and the resulting spectra.

The secondary science education majors enrolled in the contemporary physics course field tested the revised and expanded version of *Solids & Light* (the 10 activities that make up the unit today) which included the new *Gas Lamp Spectroscopy* computer program. The results of this field test indicate that the new materials and the computer program were very effective in showing the relationship between spectra and electronic transitions. These results illustrate how the computer can enhance student conceptual understanding of physics principles when the software has been designed with specific student difficulties in mind (Grayson, 1990). These initial field tests also revealed the need to streamline the instructional units in terms of the number of questions found in the instructional activities. Feedback from students revealed the need to eliminate redundant questions that do not add to their conceptual understanding and are perceived as "busy" work by the students.

In addition to field tests done at Kansas State University, a number of secondary and college faculty throughout the country have had the opportunity to field test *Solids & Light* and the other instructional units in their physics classrooms since March of 1996. These field testers were a collection of high school and college physics teachers who heard about the materials through workshops, paper presentations, and exhibits conducted by the KSU Physics Education Research Group at various conferences held by the American Association of Physics Teachers, National Science Teachers Association, National Association for Research in Science Teaching, and Kansas Association of Teachers of Science. Some of the field testers were teachers from a mailing list containing the names of several hundred college and university teachers who have received information about *Physics InfoMall* (Fuller & Zollman, 1995). Some field testers were teachers who found out about the project through *Visual Quantum Mechanics* World Wide Web home page and some were teachers who communicated an interest in the *VQM* materials as a result of personal communications with members of the group.

Physics teachers who were interested in field testing the *Solids & Light* and the other instructional units were sent information about the *VQM* project and the instructional units available for field testing. (See Appendix 1-1 for a copy of the *Teaching Units Available*.) A letter was also enclosed describing an offer made to potential field testers that if they agreed to field test the materials and if they provided feedback within a certain period of time, their small deposit would be refunded. (See Appendix 3-1 for a copy of the letter sent to potential field testers.) The potential field tester was also requested to complete a secondary school or university application form which asks for background information including the level of physics courses taught, classroom enrollment and cultural/gender make-up, percentage of class time spent on modern physics topics, school profile (student enrollment, cultural and gender makeup, school setting), teaching experience, extent of computer use in the classroom, and ordering information for any of the instructional units and supporting materials. (See Appendix 3-2 for a copy of the Secondary School application form.)

Feedback from the *Solids & Light* field tests conducted in the Spring of 1996 revealed that visual features of a computer program can result in student and teacher difficulties. The computer program, *Bound States* was developed to be used initially in *Waves & Wave Functions* (Grabhorn, Rebello, & Zollman, 1996). The use of *Bound States* in *Solids & Light* was pedagogically sound for two reasons - (1) the program allows students to determine the allowed energies for an electron bound to an atom which could be represented by a potential energy diagram of any shape (i.e. Figure 1-1 or Figure 1-2), and (2) no other computer program was available at the time. In addition to displaying the allowed energies, the program also illustrates the corresponding wave function which is an indirect representation of the probability of electrons having these certain energies. When the students and instructor observed the wave functions, they were under the false impression that the wave functions which appeared on the right of the screen were an important component to understanding the allowed energies of an electron. These wave functions were not the focus of any *Solids & Light* activity and were just an extra component on the screen. When the instructor and students observed the wave functions, however, they felt they could not continue with the activity, and some stopped at that point because the students had no prior knowledge of waves and wave phenomena. This reaction was not the intended result of using this computer program within the context of *Solids & Light*. The prerequisites of *Solids & Light* did not require students to have any prior knowledge of waves or wave functions. This field test revealed that any visualization technique that is not relevant to a particular activity or exercise should be eliminated to prevent any student or teacher misconceptions from occurring. As a result of this field test, *Bound States* was eliminated from *Solids & Light* and was replaced with the more applicable and “user-friendly” computer program, *Energy Band Creator*, in the Fall of 1996.

In spite of having this difficulty, the students and instructor were both comfortable with interacting with the concepts, materials, and computer programs. The instructor felt the materials were right on target in developing conceptual understanding of the quantum principles being introduced and relating these principles to modern everyday devices (Escalada, Rebello, Gruner, & Zollman, 1997).

3.2 Selection of Observation Field Test Sites

The majority of the student and instructor feedback collected from secondary and college field tests have relied on indirect, self-reported questionnaires (Gruner & Zollman, 1996). An important and essential component to any evaluation must include the ability to collect information directly from the source -- the students and teachers who are implementing the materials in their classroom -- in order to determine the applicability and effectiveness of these materials. An important aspect of this study was to observe directly the implementation of *Solids & Light* in a variety of high school settings (urban, suburban, rural), levels of physics courses (conceptual physics, regular first year physics, and Advanced Placement or honors physics), and teachers with a wide range of experiences. The objective was to evaluate *Solids & Light* in wide range of physics classroom environments to determine if the unit could be implemented successfully into the existing high school physics curriculum and if they could help students make observations and develop conceptual understanding of quantum principles in a variety of settings. Although the *VQM* instructional units were intended for the introductory physics curriculum at high schools and colleges, both levels, the focus of this study was at the secondary level because one would expect that high school physics teachers would be more likely to integrate the materials into an already existing curriculum as opposed to post-secondary physics faculty who would be more likely to use the materials as an independent course for non-science majors (Zollman, 1994b).

Based on email communications, personal visits, and a review of the applications received from potential field testers; four high school physics teachers were selected for the direct observation of the implementation of *Solids & Light* in their respective classrooms. These teachers and their classrooms were selected based on the criteria that they differ in the type of high school settings, availability of resources (i.e. computers and equipment), how they use the computer, and level of physics courses. The teacher being able to schedule the dates of these field tests during the Fall 1996 semester was also an important consideration. These high school field testers were sent a letter along with an informed consent form that described the purpose of the observation and formally requested permission to observe the implementation of *Solids & Light* in their classrooms. (See Appendix 3-3 for copies of the letter and consent form.)

Once the request to observe the physics classroom was approved by the instructor and a date and time for the observation was scheduled, letters and informed consent forms were sent to the Chairperson of the Science Department, the principal of the school, the students, and their parents. (See Appendices 3-4 through 3-5 for copies of these letters and consent forms.)

Upon completion of the implementation, the aforementioned parties at each field test site were sent a letter of appreciation for participating in the study. (See Appendix 3-6 for a copy of the letter.) Throughout this study and in future publications and reports about this study, we promised anonymity to the students, instructors, and schools.

3.3 Student and Teacher Populations

The first observed field test took place during the last three weeks of October, 1996, in a private, secondary boarding school located in New England. The student enrollment at the boarding school was about 1000 students with the majority of the students being white (60%) followed by Asian students (25%), African American students (10%), and Hispanic students (5%). The learning environment at the boarding school was unique in that each class had a maximum enrollment of twelve students and the interactions between the instructor and students focused on round-table discussions. Students attend courses in the morning and late afternoon with meetings and extracurricular activities scheduled during the early afternoon Monday through Saturday.

The physics department at this school consisted of eight physics teachers. The physics courses ranged from conceptual-based to calculus-based physics. *Solids & Light* was implemented in a one semester, special topics modern physics course which is typically not taught in high schools. The course focused on contemporary physics topics such as quantum physics and relativity within the context of pivotal experiments and computer simulations. The photoelectric effect and the Millikan oil drop experiments were completed by the students just prior to the field test. Two classes of the modern physics course were offered with one class having an enrollment of eight students and the other class having an enrollment of ten. The students enrolled in the course were second-year physics students who were seniors (15) and juniors (3) with strong mathematical backgrounds. Although the boarding school consisted of about 50% female students and 50% male students, the modern physics course consisted of only three female students. These numbers are consistent with studies that have shown that girls have a lesser tendency to take advanced science courses in high school (Catsambis, 1994; Campbell, 1993).

The students had access to resources like computers and other electronic equipment not typically found in public schools. The computer facilities in the science department consisted of a computer lab of five Power Macintosh™ System 7 computers with complete network/Internet connections and computer-based laboratory tools, and programs to collect and analyze physical data. The science department also had access to a number of Macintosh™ Power Books and colored monitors.

The instructor of the modern physics course at the boarding school (referred as Teacher A in this study) was certified to teach physics. He had 8 years of teaching experience, received his BA in physics in 1987, and taught courses in both physics and astronomy.

Teacher A used computers for instructional purposes in the classroom and laboratory and for grading and record keeping. Teacher A's classroom had a video monitor which could be connected to a computer and used to demonstrate computer programs to the class. For the modern physics course Teacher A had the students use computers in both the classroom and laboratory.

The second field test took place two weeks before Christmas vacation in a public, suburban New England high school. The high school had an enrollment of about 1300 students with the majority of the students being white (91%) followed by Asian students (3%), black students (3%), Hispanic students (2%), and Native Indian students (1%). The levels of physics courses at the school ranged from conceptual-based physics to Advanced Placement physics (algebra-based). The physics department consisted of three physics teachers. Two of the three physics teachers agreed to field test *Solids & Light*. These two teachers will be identified in this study as Teacher B and Teacher C.

Teacher B received his BS in physics in 1966 and did graduate work in geophysics. For 30 years, he has taught various courses including life science, earth science, electronics, and physical science. He was certified to teach math, physics, general science, and earth science. During this field test, Teacher B implemented *Solids & Light* in four sections of a conceptual-based physics course. Each section enrolled about 21 students. Prior to *Solids & Light*, Teacher B had just completed the topic of Newton's laws and had his students work on various special projects (i.e. catapaults) during the semester. His teaching approach utilized guided learning with open-ended questions in the form of worksheets. About 50% of the students in this course were female. About half of the students were seniors and the other half were juniors.

Teacher C received his BS in Chemistry in 1969 and his MA in physics teaching in 1974. He taught for 26 years and was certified to teach chemistry, physics, and math. He implemented *Solids & Light* in an algebra-based physics course in which he taught two sections with each section enrolling about 20 students and in an accelerated physics course of 25 juniors. The instructor had just completed the topic of energy conservation and would began torque and angular momentum after Christmas. His teaching approach was one that was traditionally based on lecture, engagement, demonstration, group work, and homework (short two-page lessons). The accelerated junior physics course was offered to those students who planned to take Advanced Placement physics the following year. In both the algebra-based physics and accelerated junior physics courses, like the conceptual physics course, half of the students were female. About 75% of the students enrolled in the algebra-based physics course were seniors, while 25% were juniors. The accelerated junior physics course contained 96% juniors and 4% seniors. Both the algebra-based and accelerated junior physics courses, unlike the conceptual-based physics course, had an extended lab period that was scheduled once every six days.

Teacher B had two personal computers (one Windows 3.1™ and the other Windows 95™) in his classroom and used them for instructional purposes as well as for grading and record keeping. One of the computers was connected to two television monitors and a closed-circuit camera so that images from either the computer screen or the camera can be displayed to the students. Teacher C had seven Apple IIe™ computers in his classroom and used them for instructional purposes in the classroom and laboratory. These computers were used extensively by his students in conducting motion experiments that utilize air tracks and gliders. Both teachers also had access to a school computer lab that contained 24 Windows 95™ computers with Internet connections.

At the same time the second observed field test occurred, field tests were also taking place in two other, nearby New England high schools with enrollments of about 900 students. At one high school, *Solids & Light* was implemented in a second year, computer-based, modern physics course which was taught by a physics teacher with 4 years of physics teaching experience (who will be referred to as Teacher D). Prior to the field test, Teacher D covered fractals, solids & light, and particle physics. At the other high school, *Solids & Light* was implemented in a senior-level honors physics course that was taught by a physics teacher with 10 years of physics teaching experience (Teacher E). Prior to the field test, she had covered light and electricity through Ohm's law. The implementation of *Solids & Light* in the computer-based, modern physics course was observed twice during the two-week field test. The implementation of the unit in Teacher E's classroom was not directly observed due to scheduling conflicts. However, correspondence via email and telephone during the implementation with both of these instructors did occur on a regular basis so valuable feedback from these field tests could be collected.

In terms of materials and equipment required for the observed field tests to take place, all the field testers excluding Teachers A and E requested breadboards, spectroscopes, alligator clip wires, and batteries. These materials in addition to the LED kits, written documents, and computer disks were provided by the KSU Physics Education Research Group. As a result of the large number of students in their physics courses, Teachers B and C needed to share the use of the materials and equipment in addition to the computer lab during the field test at the public high school.

3.4 Research Questions

This study was designed to determine the applicability of *Solids & Light* in these high school physics environments by utilizing a combination of quantitative and qualitative research techniques. The research questions addressed by this study were the following:

Research Question #1a:

> How is *Solids & Light* being implemented in various high school physics classrooms and how is the implementation affected by the level of physics course, the availability of resources, and teacher's teaching style and background?

Research Question #1b:

> How are the resulting student and teacher interactions with the *Solids & Light* materials and one another consistent with the learning cycle and how are these interactions affected by the level of physics course, the availability of resources, and the teacher's teaching style and background?

Research Question #1c:

> What are students and teacher difficulties and misconceptions associated with the implementation of *Solids & Light* in the physics classroom and how are these difficulties and misconceptions related to the level of the physics course, availability of resources, and the teacher's teaching style and background?

Research Question #2:

> What are students' attitudes toward the *Solids & Light* materials and the associated instructional strategies and how are these attitudes affected by the level of physics course, computer usage, the teacher's teaching style and background, gender, and students' attitudes toward physics and computers?

Research Question #3:

> What are teachers attitudes toward the *Solids & Light* materials and the associated instructional strategies and how are these attitudes affected by the level of physics course and the teacher's teaching style and background?

Research Question #4:

> How effective are the computer programs, materials, and instructional techniques utilized in *Solids & Light* in helping students make observations and develop conceptual understanding of the quantum principles being introduced?

3.5 Data Collection Instruments

The following instruments were used in this study to collect data that addresses these research questions. To be able to answer these questions, we must use data collection instruments that are both quantitative and qualitative in nature and that involve various data sources. According to Lincoln & Guba (1985) the use of multiple quantitative and qualitative instruments in addition to a variety of data sources provides a complete description of events, behaviors, setting, and the environment in which the implementation takes place which is essential in determining credibility and applicability.

A Scale to Measure Attitudes Toward Physics

The *Purdue Master Attitude Scale* known as the *Attitude Toward Any School Subject - Form A* was slightly modified to be applicable for physics classrooms and to be used to measure student attitudes toward physics. (See Appendix 3-7 for a copy of this instrument). The 17-item instrument, developed by Remmers (1960), is a shortened form of a 40-item instrument constructed by Silance and Remmers. The *Purdue Master Attitudes Scales* were developed to measure attitudes towards any school subject, vocation, institution, defined group, proposed social action, practice, home-making activity, and high school, and to measure individual and group morale. The validity of the scales has been established in numerous studies (Shaw & Wright, 1967; Remmers, 1960).

In this study the *Scale to Measure Attitudes Toward Physics* (SMATP) determined if students from different physics classroom environments had varying degrees of attitudes toward physics and if these attitudes had any affect on their attitudes towards the *Solids & Light* materials. Cottle and Lunsford (1995) found that student attitudes toward physics can influence the physics classroom environment by affecting student motivation and participation as well as student attendance and retention rates. According to Atwater and her colleagues (1985) attitudes and achievement among adolescents are associated with parental and family influences, self-concept, locus of control, achievement motivation, class climate, teachers, and attitudes toward subject matter.

The SMATP presents seventeen statements and asks students to mark a plus sign next to each one with which they agree. The attitude score is the median scoring scale value of the statements marked with a plus sign. (See Appendix 3-8 for a copy of the scoring table.) The instrument has been used to compare the attitudes toward physics of students enrolled in traditional physics course with attitudes toward physics of students enrolled in modern physics course (Nance, 1972) and attitudes toward physics of college students (Gruner, 1997).

This instrument was selected for this study rather than the longer 40-item instrument because only one slight modification in wording would have to be made (i.e. pasttime changed to hobby) to make it consistent with current vocabulary and because the instrument could be completed in less than five minutes. Although the longer form may be expected to be more reliable (Shaw & Wright, 1967), the primary objective of this study was to assess the effectiveness of implementing *Solids & Light* in the classroom and not to burden either the students or the teacher with completing an excessive number of instruments. The SMATP was administered to the students prior to the observation of classes so as not to interfere with the actual field test.

The *Scale to Measure Attitudes Toward Physics* could have been administered as a pre-test before students begin working on *Solids & Light* and as a post-test after the completion of the unit to determine if the materials had any affect on students attitudes toward physics. However, a time period of two-weeks (the time estimated to complete *Solids & Light*) would not be sufficient for student attitudes toward physics to change drastically. As a result, the instrument was administered only to measure students attitudes toward physics prior to the field test.

Attitudes Toward Computer Technologies Instrument

Prior to the observed field tests, the students also completed the portion of the *Attitudes Toward Computer Technologies* (ATCT) instrument that measures student feelings of comfort/anxiety in using computer technologies. The ATCT is a 19-item Likert-type questionnaire with 11 items measuring perceived usefulness of and 8 items measuring perceived comfort/anxiety with computer technologies. The instrument utilizes a 4-point response format in which students are asked to indicate their level of agreement or disagreement. The instrument was initially developed and validated for the use with teacher education students and practicing teachers by Delcourt and Kinzie (1993).

The ATCT instrument was used with introductory physics students in a recent study that examined the effects of using interactive digital video computer programs on students attitudes toward computer applications such as computer software and computer video equipment (Escalada & Zollman, 1997; Escalada, Grabhorn, & Zollman, 1996). The instrument was used in the present study because of the significant role that interactive computer programs play in the introduction and development of quantum principles in *Solids & Light*. Kulik, Kulik, and Bangert-Downs (1985) encourage the evaluation of any computer-based education in terms of attitude towards computers, student attitude toward instruction and subject matter and also amount of time needed for instruction. According to Lloyd and Gressard (1984), an instrument that measures computer attitudes could aid in the evaluation of new programs or in the identification of potential problems in implementing curriculum changes.

The ATCT instrument was also used in this study to determine if students from different physics classrooms had varying degrees of comfort/anxiety levels in using computers and to determine if these attitudes affected their interactions with the *Solids & Light* computer programs and their ability to learn from these programs. Only eight items (those items that measure students' feelings of comfort/anxiety in using computers) of the original ATCT instrument was used for this study. In these items the term computer applications was changed to computers to make it more applicable to the present study. (See

Appendix 3-9 for a copy of this instrument.) This modification did little to affect the content of the items found in the ATCT instrument. Because only eight items of the ATCT instrument were administered to the students, the instrument could be completed in less than about 5 minutes, which makes the instrument very convenient to use.

Student responses for the eight-item Likert statements are allocated numerical values where strongly disagree is scored 1 and strongly agree is scored 4 for positively phrased items. For negatively phrased items, the scoring is reversed. The individual scores for each factor are summed to yield a total score. The scores can range from 8 to 32, with 20 being the neutral score. Any individual with a score greater than 20 has positive attitudes toward using computers with high scores associated with feelings of comfort about the prospect of using computers. Any score that is less than 20 indicates negative attitudes toward using computers with the lower scores associated with feelings of anxiety about the prospect of using computers.

Instrument for Analysis of Science Teaching

The important features of this study were the opportunities to observe directly how *Solids & Light* was implemented in the various physics classroom environments. These observations were conducted by a series of twenty-minute observations with the *Instrument for Analysis of Science Teaching* (IAST). The IAST (Hall, 1971) is a modified version of Flanders' *Interaction Analysis* instrument (1970). *Interaction Analysis* is an observation instrument designed to examine teacher-student interaction (verbal behavior) in the classroom and is best-known, frequently used, and easily adapted to all grade levels and subject-matter areas (Borich & Madden, 1977; Standford & Roark, 1974; Flanders, 1970).

The *Instrument for Analysis of Science Teaching*, like the Flanders' instrument, allows the observer to code the teacher's and students' observable behavior live, on-the-spot, as interaction occurs, using a pre-established category system. Like the Flanders' instrument, the IAST enables the observer to analyze the observable classroom behavior according to the degree to which the teacher restricts or expands the students' freedom to perform (Stanford & Roark, 1974). The instrument also allows the observer to study the types of instructional strategies employed by the teacher as well as observable classroom behavior exhibited by the student. The IAST instrument has 14 categories (compared to 10 categories for the

Interaction Analysis instrument) which are indicated below. The first eight categories are designated for observed teacher-behavior, categories 9 - 12 are designated for observed student-behavior, and the last 2 categories are special categories. All categories, except for category 12, focus on observed verbal behavior.

1. **Accept feelings:** Recognizes and identifies with feelings of students (empathetic), provides non-evaluative encouragement, or jokes with a positive affective response.
2. **Praise:** A positive value judgment.
3. **Acceptance of student's statements:** A restatement of student's statement, either written on the board or verbal. This category would also include short, non-evaluative confirmation such as "okay" or "all right".
4. **Question:** All questions that requires a student response.
5. **Direction:** Giving directions and procedures; telling students how to do something. This requires an immediate student response or behavior.
6. **Initiate Substantive Information:** Lecturing, giving facts, calculating, including writing new information on the board, and reviewing information.
7. **Justification of Authority:** Disciplinary action or criticism of a student's behavior.
8. **Teacher Controlled Silence:** Periods of silence which would be associated with the teacher presenting a demonstration or examining his or her notes.
9. **Student Statements:** All student statements that are not questions and involved some interaction with the teacher. This category is used for a small group discussion which included the teacher.
10. **Student Questions:** Questions asked by the students of one another or of the teacher.
11. **Affective Response:** Student responses that reflect student emotions or feelings (positive or negative) about a certain topic.
12. **Student Activity:** Activities such as students working in workbooks, reading silently or aloud, or working with scientific apparatus, etc.
13. **Student-to-Student Interaction:** Interactions among students without the involvement of the teacher. This category is used for small group discussions in which the teacher was not included.
14. **Non-functional Behavior:** Classroom behavior without direction or purpose where no effective instruction is occurring.

The *Instrument for Analysis of Science Teaching*, unlike *Interaction Analysis*, enables the observer to continue categorizing whenever the classroom activity is changed to a situation when students are working on an activity or doing silent reading and to some degree when small groups of students are working around the classroom (Marshall & Rossman, 1995). If *Interaction Analysis* was used during these situations the observer would be required to stop classifying as a result of the observing being inappropriate (Amidon & Flanders, 1967). Thus, the IAST is more conducive and appropriate to use than *Interaction Analysis* in categorizing classroom behaviors that are typically found in science or physics classrooms where laboratories are an integral component of instruction. For this study, category thirteen was modified from the original IAST to eliminate the requirement of the teacher or class listening and to allow the observer to differentiate between this category and category nine when students in small groups or in a class are talking with the teacher present. In addition, category twelve was modified to include students reading the activities out loud so that the observer could make a distinction between this behavior and the type of behavior that is described in category thirteen.

Prior to categorizing the observed behavior, the observer spends a few minutes getting familiar with the learning environment (Amidon & Flanders, 1967). The observer is situated so that he or she can see both the teacher and students. During a twenty-minute period, the observer records and tallies for every 3 seconds the observed classroom behavior in one of fourteen pre-established categories on a sheet of paper. The intent of the observed behavior is ignored and only the actual behavior is recorded (Stanford & Roark, 1974). In addition, the observer makes marginal notes of the kinds of events that occur in the classroom as they happen. Classroom behaviors are recorded and tallied on this sheet of paper by beginning and ending with category 14 based on the assumption that each record begins and ends with non-functional behavior and because of convenience (Hall, 1971; Amidon & Flanders, 1967).

Once the observed classroom behaviors are categorized, the identified categories are then arranged by using a 14 x 14 matrix which provides a visual diagram of the classroom interaction pattern (Hall, 1971). The tallies are arranged by the observer moving his or her finger down the left-hand column until the first category (which is always a 14) is found. (See the copy of a sample scoring matrix found in Appendix 3-10.) Once the first category is found, the observer then moves his or her finger across the matrix until the finger intersects the cell of the second category. The tally is then placed in that cell. The second category is then found on the left-hand column and the process is repeated until the last classroom behavior (which is always a 14) is arranged in the matrix. The number of tallies for each column and row are then added to obtain a total of tallies for each observed category. The number of tallies for each category obtained from each row should equal the number of tallies for each category obtained from each column. The total number of tallies for the twenty minutes period is obtained by adding the number of tallies observed for each category and the percentage of each observed category is then calculated from these totals.

The matrix allows the observer to differentiate each category of observed behavior and to classify the pattern of behavior observed as student-controlled or teacher-controlled. One of the unique aspects of the interaction analysis scheme is that the sequence of the categories recorded on the sheet of paper during the observation is still preserved when they are placed in the matrix. The ratio of student-controlled behavior to teacher-controlled behavior can be determined by dividing the sum of the tallies found in categories 9 through 10 by the sum of the tallies found in categories 1 through 7 (Hall, 1971). Although the IAST matrix provides a visual diagram of the classroom interaction pattern that allows the observer to determine the observed pattern of behavior as being student-controlled or teacher-controlled, the computation of the student/teacher ratio coupled with the percentage of tallies recorded in each observed category provides the same information in a quantitative form which allows for valid comparisons with data collected by other observers. For this study, the computation of the student/teacher ratio and the percentage of tallies recorded in each observed category determined the degree of student interaction with the *Solids & Light* materials and computer programs. The student/teacher ratio was used to indicate whether or not the observed classroom behavior was consistent with the type of learning cycle activity being completed at the time of the observation. For example, if the students were completing an exploration activity the degree of student interaction with the materials should be high (indicated by a large value for the student/teacher ratio) if the activity was exploratory in nature. A concept introduction activity might be indicative of a small student/teacher ratio if the teacher presented the activity in a lecture-format. The student/teacher ratio quantitatively addresses the research question of how the teacher implements each activity of *Solids & Light* and whether or not the resulting the resulting student and teacher interactions with the materials were consistent with the type of learning cycle activity being completed.

Although categories 11 through 13 could be classified as student categories and category 8 could be classified as a teacher category, Hall (1971) does not include these categories in the computation of his student/teacher ratio so that the categories involved in the computation are similar to the categories used by

Flander's *Interaction Analysis* to calculate his student/teacher ratio. While category 14 can be classified as either student or teacher controlled depending on the situation, categories 8 and 11-13 can be argued to be teacher-controlled and student-controlled respectively especially in an activity-based learning environment. Thus, for this study the student behavior was classified as categories 9-13 and the teacher behavior was classified as categories 1-8. Because the percentages computed for the various categories were determined by the procedures dictated by Hall (1971) and Flanders (1970), the addition of these categories to the computation of the student/teacher ratio would not affect the validity of the IAST.

The IAST scoring matrix also allows the observer to determine the ratio of indirect behavior (behavior that provide opportunities for the student to interact with the teacher- categories 1-4) to direct behavior (behavior that places more control with the teacher- categories 5-7) and the revised ratio of indirect behavior (categories 1-3) to direct behavior (categories 5 and 7) which indicates how the teacher handles motivation and control behaviors. These ratios were not used in this study because they focus on teacher behaviors rather than student or teacher interactions with the *Solids & Light* materials.

In using the *Instrument for Analysis of Science Teaching*, the observer can categorize classroom behavior live or from recordings (audio or video). For this study, the observed classroom behavior was categorized both live and from videotaped recordings. These recordings were used so that a colleague could categorize observable classroom behaviors which would allow comparisons of the original observer's categories with a colleague's categories to establish reliability.

Reliability was determined by using Scott's Method (Flanders, 1967; Scott, 1955) because it is unaffected by low frequencies, can be adapted to percent figures, can be estimated more rapidly in the field, and is sensitive at higher levels of reliability. The method involves the computation of the coefficient, Π, and is represented by the equation:

$$\Pi = \frac{P_0 - P_e}{100 - P_e},$$

where P_o is the proportion of agreement (which is determined by subtracting the sum of the absolute differences in percent figures for each category between the two observers from 100) and P_e is the proportion of agreement expected by chance (which is determined by the sum of the squared averages of the two observers' percent figures for each category). A Scott coefficient of .85 or higher is considered to be a reasonable level of performance (Flanders, 1967).

The second observer was trained in using the IAST by using the sample data provided in the IAST manual (Hall, 1971) and by using videotaped segments of two observed activities that took place at one of the high schools which were transcribed. As part of the training and after discussing the modifications made to the IAST with the original observer, both observers categorized classroom behavior from the written transcriptions and compared their categorizations. Any discrepancies were discussed and reconciled. In addition, both observers categorized the observed behavior from the two videotaped segments and their categorizations were compared. Any discrepancies were discussed and reconciled.

To determine the degree of teacher instruction or guidance provided at the start of each activity, the IAST was used to categorize observed classroom behavior during the first twenty minutes of each class. During the rest of the class period, informal observations were made and recorded in field notes. With the exception of the accelerated junior physics course at the public high school, each type of physics course involved more than one class. (See Table 3-1.)

Table 3-1: Observed Physics Classroom Environments

Type of Course	Number of Classes	Total Number of Students	Instructor
Modern Physics	2	18	Teacher A
Conceptual Physics	4	84	Teacher B
Algebra-based Physics	2	38	Teacher C
Accelerated Physics	1	25	Teacher C

Although the observations of the two modern physics classes at the private boarding school did not pose a scheduling problem, a problem did arise in scheduling observations of Teachers B and C teaching three levels of physics with a total of 7 classes (including the accelerated junior physics class) at the public high school. As a result, a few of the physics classes did overlap and prevented observations of all classes during the implementation. At both schools, as many of the physics classes as possible were observed and classroom behavior was categorized to develop the observer's skill in categorizing classroom behavior.

Solids & Light Assessment Questions

Eight short-answer questions were developed to assess conceptual understanding of the quantum principles introduced in *Solids & Light*. (See page 46-52 of the *Solids & Light Instructor's Manual* found in Appendix 1-2.) These qualitative questions, originally developed for the secondary science education undergraduates who field tested the unit in the spring of 1996, were designed to be administered to the students upon completion of the last activity. The field test instructors had the option of not administering these questions to his or her students upon completion of the field test. Two of the three instructors (Teachers A and C), gave their students an exam that contained these questions or modified versions of these questions and reported the results of these exams. Teacher C administered the same exam to both his accelerated junior physics and algebra-based physics students.

Student Questionnaires

The *Solids & Light* student evaluations consisted of open-ended questions in which the students were asked to summarize what they learned and what they found to be the most interesting about the *Solids & Light* activities. The evaluations also included a Likert-type questionnaire in which the students were asked to rate on a scale from one to five how they felt about the instructional techniques, the potential energy diagram as a model of the atom, and the computer programs in terms of its usefulness or effectiveness in helping students understand or make observations. (See Appendix 3-11 for a copy of the *Solids & Light Student Questionnaire*.) The students were asked to complete these forms upon completion of Activity 5 and Activity 9 or 10 of *Solids & Light*.

Student responses for the Likert-type items were categorized according to the type of instructional strategies utilized in *Solids & Light*. The following categories resulted: exploration (4 items), the use of potential energy diagrams (2 items), written materials providing adequate directions (1 item), developing understanding (2 items), recommendation (1 item), and computer programs (4 items). The computer programs category was further divided into the following subcategories: *Spectroscopy* (1 item), *Energy*

Band Creator (2 items), and *Semiconductor Device Simulator* (1 item). The mean scores for these categories and subcategories were tabulated to quantify students' general attitudes toward these strategies.

Instructor Questionnaires

The teacher evaluation forms follow the same format as the student evaluation in that it contained both open-ended questions and Likert-type items. In the form of open-ended questions teachers were asked what their students learned by doing the activities and whether their students met the prerequisites required to complete the activities. (See Appendix 3-12 for a copy of the *Solids & Light Instructor Questionnaire*.) In addition, the teachers were asked to identify any difficulties their students had with any of the experiments or the concepts found in the activities, the amount of time required for their students to complete each activity, and what modifications were made to the activities.

The teachers used a Likert-type scale to rate the overall effectiveness of the instructional techniques utilized in the activities in helping the students make their observations and understand the objectives of the instructional units. Teacher responses to these items were categorized as: electrical explorations of LEDs (9 items), spectral explorations (4 items), questions (4 items), explanation (3 items), potential energy diagrams without computers (1), *Spectroscopy* (1 item), *Energy Band Creator* (3 items), and *Semiconductor Device Simulator* (1 item). The mean scores for these categories were tabulated to quantify teachers' general attitudes toward these categories. The instructors were asked to complete these forms at the end of Activity 5 and again at end of Activity 9 or 10.

In addition to the aforementioned data collection instruments, extensive field notes were kept and informal interviews were used to collect data from all the teachers observed so that sufficient descriptive data would be collected in order to determine applicability. Teacher C also allowed an informal interview of his students immediately following the completion of the field test.

3.6 Experimental Design

The objective of this study was to determine the applicability of *Solids & Light* in the various observed physics classroom environments by examining the effectiveness of the unit and the associated instructional techniques to help make observations and develop conceptual understanding of quantum principles. Applicability, which falls under a qualitative research paradigm, should not be confused with generalizability (external validity), which falls under the quantitative research paradigm. As a result of the high degree of variability found in these various physics classroom environments, this study addresses the question of applicability. In addressing applicability this study focuses on determining if *Solids & Light* can be successfully implemented in environments similar to the ones described. Thus, the key in establishing applicability is to provide enough description to make such decisions possible (Lincoln & Guba, 1985).

The various observed physics classroom environments consisted of the following: two modern physics classes at the boarding school and four conceptual physics classes, two algebra-based physics classes, and one accelerated junior physics class from the public high school. This quasi-experimental study was a modified version of a non-equivalent control group design as a result of all classes being given pretest and posttest measures and the lack of random assignment that existed in the sample.

The pretest measures for this study included *A Scale to Measure Attitudes Toward Physics* and the *Attitudes Toward Computer Technologies* instrument. The posttest measures included *Student* and *Teacher Solids & Light Questionnaires* for all classes and assessment questions for the modern, algebra-based, and accelerated junior physics classes. This study was a modified non-equivalent control group design in that the pretest measures were not the same instruments as the posttest measures and the treatment (which was the *Solids & Light* materials) were given to all classes. As a result, the limitation of this study was that only valid comparisons can be made between the various observed classes in terms of the pretest and posttest measures separately. No pretest-post-test comparisons could be made between classes.

A one-way ANOVA (analysis of variance) was calculated for both student physics attitudes scores and computer attitudes scores across courses. T-tests for independent samples were calculated for male and female student physics attitudes scores as well as male and female student computer attitudes scores for the entire student sample.

One-way ANOVA’s were calculated for student ratings of the various non-computer categories determined from the student questionnaires across groups. T-tests for independent samples were calculated for male and female ratings on these categories. An ANCOVA (analysis of covariance) was calculated for comparing student scores on the recommendation category with student physics attitudes as a covariate.

One-way ANOVA's were calculated for student ratings of the various computer programs determined from the student questionnaires as well as a total computer program rating (determined by adding the scores for all items that involved computer programs) across groups. T-tests for independent samples were calculated for male and female ratings on these categories. An ANCOVA was calculated for comparing student total computer rating scores with student computer attitudes as a covariate.

The qualitative data collected from the student and instructor questionnaires, *Instrument for Analysis of Science Teaching*, and the assessment questions were analyzed and summarized so that comparisons between courses may be made. A t-test for independent samples was calculated to compare the mean test scores of Teacher C's students who were administered the same test.

Table 3-2 summarizes the research questions, data collection approach, respondents, and data analysis plan used in this study.

Table 3-2: Summary of Research Design & Data Analysis Plan

Research Question #1a:

How is *Solids & Light* being implemented in various high school physics classrooms and how is the implementation affected by the level of physics course, the availability of resources, and the teacher's teaching style and background?

Research Question #1b:

How are the resulting student and teacher interactions with the *Solids & Light* materials and one another consistent with the learning cycle and how are these interactions affected by the level of physics course, the availability of resources, and the teacher's teaching style and background?

Research Question #1c:

What are student and teacher difficulties misconceptions associated with the implementation of *Solids & Light* in the physics classroom and how are these difficulties and misconceptions related to the level of the physics course, availability of resources, and the teacher's teaching style and background?

Data Collection Approach	Analysis Plan	Respondents
Instrument for Analysis of Science Teaching and informal observations	Analyze observed behavior, categories, and student/teacher ratio.	Students/Teachers
Instructor Questionnaires	Analyze descriptive comments and ratings.	Teachers
Student Questionnaires	Same.	Students
Assessment Questions	Analyze scores and responses.	Accelerated, Algebra-based, and Modern Physics Students
Informal Interviews	Analyze comments.	Teachers and Accelerated and Algebra-based Physics Students

Research Question #2:

What are students' attitudes toward the *Solids & Light* materials and the associated instructional strategies and how are these attitudes affected by the level of the physics course, computer usage, the teacher's teaching style and background, students' gender, and students' attitudes toward physics and computers?

Data Collection Approach	Analysis Plan	Respondents
Student Questionnaires	Analyze descriptive comments, establish categories, and One-Way ANOVA.	Students
Scale to Measure Attitudes Toward Physics	T-test & ANCOVA.	Students
Attitudes Toward Computer Technologies Instrument	T-test & ANCOVA.	Students
Instrument for Analysis of Science Teaching and informal observations	Analyze observed behavior and categories.	Students/Teachers

Research Question #3:

What are teachers attitudes toward the *Solids & Light* materials and the associated instructional strategies and how are these attitudes affected by the level of physics course and the teacher's teaching style and background?

Data Collection Approach	Analysis Plan	Respondents
Instructor Questionnaires	Analyze descriptive comments and ratings.	Teachers
Informal Interviews	Analyze descriptive comments.	Teachers

Research Question #4:

How effective were the computer programs, materials, and instructional techniques utilized in *Solids & Light* in helping students make observations and develop conceptual understanding of the quantum principles being introduced?

Data Collection Approach	**Analysis Plan**	**Respondents**
Instructor Questionnaires	Analyze ratings and descriptive comments.	Teachers
Assessment Questions	Analyze responses and exam scores (including t-tests).	Accelerated, Algebra-based, and Modern Physics Students
Informal interviews and observations	Analyze comments and observations.	Teachers and Accelerated and Algebra-based Physics Students

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Student Attitudes Toward Physics and Computers

To determine if students in different levels of physics had varying degrees of attitudes toward physics and comfort levels in using computers, the *Scale to Measure Attitudes Toward Physics* (SMATP) and the *Attitudes Toward Computer Technologies Instrument* (ATCT) were administered as a pretest to all the students participating in the observed field tests. Table 4-1 summarizes the student SMATP mean scores categorized by course, school, and teacher. The lowest and highest possible scores on the SMATP are 1.0 and 10.3 respectively.

Table 4-1: Student Means (and Standard Deviations) for the SMATP by Course

Conceptual Physics	Accelerated Physics	Algebra-based Physics	Modern Physics
7.92^{1a}(.92) n = 70 *Teacher B@HS*	6.95^{2} (1.70) n = 43 *Teacher C@HS*	6.68^{1} (1.70) n = 31 *Teacher C@HS*	$8.40^{1a,2a}$ (.38) n = 17 *Teacher A@BS*

Above means failed test for Homogeneity of Variances at $p < .05$.

^{1,2} Denotes significantly different on adjusted One-Way ANOVA and post hoc comparison test at $p < .05$.

$^{1a,\ 2a}$ Denotes significantly larger values.

The resulting student SMATP mean scores shown in Table 4-1 indicate that all students had positive attitudes toward physics. The modern physics students from the boarding school had a higher SMATP mean score and their scores were more homogeneous than the public high school physics students. Because only the modern physics students from the boarding school were second year physics students with similar mathematical backgrounds, these results are expected. Students who would elect to take physics for a second year would also be more likely to have positive attitudes toward physics.

The interesting result from Table 4-1 is that the SMATP mean score for the conceptual physics students was higher than the mean scores for the accelerated junior physics and algebra-based physics students. This result indicates that students attitudes toward physics depends not only on the physics course but also on the teacher and his or her teaching style.

A One-Way ANOVA revealed that at least two of the mean scores shown in Table 4-1 were significant at the .05 level. (See Table 4-2.) However, a test of homogeneity of variance (a necessary assumption of the ANOVA to prevent inflation of a Type I error) indicated that the variances were not equal. In such cases where the variances are heterogeneous and the sample sizes are not equal, Keppel (1991) recommends that the degrees of freedom for the within-group be modified to take into account these characteristics. Table 4-2 shows that the unadjusted F test and adjusted F test (called the Welch test) were both significant and revealed that at least two of the SMATP mean scores were significantly different.

Table 4-2: ANOVA Summary for the SMATP Across Course Levels

Source	**df**	**MS**	**F**
Course	3	17.99	11.69* (Unadj)
Unadjusted Error	137	1.54	6.02* (Adj)
Adjusted Error	71	2.99	

* p < .05

Table 4-1 shows the results of a post-hoc comparison test in which the within-group degrees of freedom was adjusted to take into account heterogeneity of variances and unequal sample sizes. Table 4-1 reveals that the SMATP mean score of the modern physics students taught by Teacher A (8.40) and of the conceptual physics students taught by Teacher B (7.92) were significantly higher than the mean score of the algebra-based physics students taught by Teacher C (6.68). The post-hoc comparison test also showed that the SMATP mean score of the modern physics students taught by Teacher A (8.40) was significantly higher than the mean score of the accelerated junior physics students taught by Teacher C (6.95). These results indicate that student attitudes towards science reflects their attitudes toward their teacher, the science curricula, and the classroom environment (Atwater et al., 1995).

Table 4-3 displays the student mean scores for the *Attitudes Toward Computer Technologies* (ATCT) instrument categorized by course, school, and teacher. Since the maximum and minimum possible scores on the ATCT are a 32 and 8 respectively, the mean scores illustrated on Table 4-3 indicate that the students participating in the study were relatively comfortable in using computers.

Based on the standard deviations shown in Table 4-3, the ATCT mean score for the modern physics students (28.18) was, like the SMATP results, higher and more homogeneous than the mean scores for the students enrolled in the other physics courses. The ATCT mean scores for the algebra-based physics students (26.03) and accelerated junior physics students (27.10) both taught by Teacher C were higher than the mean score for the conceptual physics students (24.68) taught by Teacher B. These differences may be due to the students experience in using computers which could be attributed to how computers are used in these perspective physics classrooms (Escalada & Zollman, 1997). Both Teachers A and C had their students use computers more extensively in their classrooms than Teacher B had his students use computers in his classroom.

Table 4-3: Student Means (and Standard Deviations) for the ATCT by Course

Conceptual Physics	Accelerated Physics	Algebra-based Physics	Modern Physics
24.68 (4.66) n = 69	27.10 (4.09) n = 21	26.30 (5.03) n = 33	28.18 (2.62) n = 17
Teacher B@HS	*Teacher C@HS*	*Teacher C@HS*	*Teacher A@BS*

Above means failed Test for Homogeneity of Variances at $p < .05$.

A One-Way ANOVA was performed to determine if at least two of the means, which are summarized in Table 4-3, were significantly different. This procedure revealed significance but failed the test for homogeneity of variance. (See Tables 4-3 and 4-4.) As a result the One-Way ANOVA was modified to take into account the unequal sample sizes and heterogeneity of variances that existed. The adjusted statistical procedure revealed that at least two of the means were not significantly different at the .05 level. (See Table 4-4.) Although the students involved in the study had various degrees of experience in using computers in their physics classroom, the level of physics course did not have an affect on student mean scores on the ATCT instrument.

Table 4-4: ANOVA Summary for the ATCT Across Course Levels

Source	df	MS	F
Course	3	73.11	3.64* (Unadj)
Unadjusted Error	136	20.09	2.72 (adj)
Adjusted Error	78	35.11	

* $p < .05$

Table 4-5 summarizes the results of comparing students' SMATP and ATCT mean scores across gender. T-tests for independent samples were conducted to determine if students' gender had any affect on student SMATP and ATCT scores. Table 4-5 reveals that, although both female and male students had relatively high mean scores on the SMATP and the ATCT, a significant difference at the .05 level existed between the female and male students only on the ATCT. Although gender did not have any affect on student attitudes toward physics, gender did have an affect on students' comfort levels in using computers.

These results indicate that the male students observed in these field tests were more comfortable in using computers than the female students.

Table 4-5: Male & Female Student Means (and Standard Deviations) for the SMATP and ATCT

Instrument	Female	Male	t-values
SMATP	7.35 (1.46) n = 67	7.77 (1.24) n = 73	$t_{obt} = 1.82$ ($t_c = 1.98$)
ATCT	24.85[1] (4.56) n = 67	26.64[1] (4.51) n = 73	$t_{obt} = 2.34$ ($t_c = 1.98$)

[1] Denotes significantly different at $p < .05$.

Based on the number of female students enrolled in each course observed (50% of the students were female with the exception of the modern physics course) and the students attitudes toward physics, physics, at least in these learning environments, was not the "great divider" between young men and women that have been reported in previously studies (Catsambis, 1994; Campbell, 1993; Horn, 1990). Both male and female students in the study both had positive attitudes toward physics.

A Two-Way ANOVA with student SMATP or ATCT scores being the dependent variable and with the factors of course and gender could have been done to test for main effects and the course-gender interaction. However, the gender group sizes were too small for each course (smaller than 15) to conduct a valid Two-Way ANOVA statistical test.

4.2 Observed Student/Teacher Interactions with Solids & Light

The *Instrument for Analysis of Science Teaching* (IAST) was used to categorize student and teacher interactions with *Solids & Light* observed live and from videotaped recordings. Table 4-6 summarizes the percentages of each observed classroom behavior (out of the total tally number) for each day of the field test that took place in the modern physics course taught by Teacher A.

On the first day in which Activity 1 (an exploration) was field tested, Teacher A gave the students brief instructions and divided the students into groups of two with each group working on one computer in the computer lab. The instructor replaced the recommended battery and resistor of the circuit apparatus with a DC power supply and the recommended multimeters with a computer-based laboratory tool. With the appropriate probes, the computer interface and a data collection and analysis computer program allowed students to collect and plot their measurements of current and voltage for each light source simultaneously on the computer screen. Prior to class time Teacher A made all the connections of the simple circuit and adjusted the settings of the computer program that was used to collect and graph the data. The circuit was connected in such a way that the students needed only to place the light source in the circuit and turn the knob of the power supply. With the click of the mouse, the computer collected and graphed the resulting data.

Table 4-6: Observed Modern Physics Classroom Behaviors (Teacher A)

Cat.	***Day 1*** **Act 1** **(vt#1)**	***Day 2*** **Act 2-3** **(vt#2)**	***Day 3*** **Act 4** **(vt#3)**	***Day 4*** **Act 1-5** **(live)**	***Day 5*** **PED** **(vt#4)**	***Day 6*** **Act 6-8** **(vt#5)**	***Day 7*** **Act 8** **(live)**	***Day 8*** **Review** **(live)**
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.3	6.7	0.9	6.4	5.4	3.1	4.8	7.1
4	1.3	6.7	2.6	14.5	8.4	8.9	13.7	12.9
5	4.9	10.7	1.1	0.6	3.2	0.0	1.6	2.5
6	6.2	47.5	14.7	37.0	44.9	51.7	43.3	41.4
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.7	5.7	1.8	6.0	14.5	12.4	9.9	4.6
9	6.6	15.0	5.9	28.8	16.2	18.0	21.0	22.9
10	4.3	4.7	8.8	3.8	2.9	3.5	3.8	6.4
11	4.6	0.0	2.9	0.0	0.0	0.0	0.0	0.7
12	31.1	2.7	29.0	2.6	4.3	0.0	1.3	0.0
13	39.7	0.0	30.8	0.0	0.0	1.1	0.3	1.1
14	0.3	0.3	1.5	0.3	0.2	1.3	0.3	0.4
Tally #	**305**	**299**	**455**	**344**	**441**	**451**	**314**	**280**
Student / Teacher	**6.44**	**0.29**	**3.67**	**0.55**	**0.31**	**0.30**	**.36**	**.45**

Note: Numbers in Regular Font Represent Percentages

During the first day the observation focused on a group of two students. Table 4-6 shows for the first 20 minutes of the first activity, which was recorded on videotape, was indicative of a high student to teacher interaction ratio. (Student/Teacher = 6.44 as shown in Table 4-6.) This focus on student interaction for the first activity was very consistent with the exploration phase of the learning cycle. The majority of the observed classroom behaviors for the first activity were category 13 - student interaction (39.7%) and category 12 - student activity (31.1%).

Teacher A assigned Activity 2 (a concept introduction) as a homework assignment. Teacher A began the second day of the field test by discussing with the entire class the results of the first two activities in a round table format. After providing instructions on how to complete the third activity (an exploration) which included how to use a spectrometer to observe spectra, Teacher A's students worked at individual lab stations in the classroom to observe spectra of several different light sources. He also had his students observe the spectra of street lamps outside of class for a homework assignment. Table 4-6 shows that the emphasis for the first 20 minutes of class was on teacher interaction (Student/Teacher ratio of .29) with the majority of the observed behaviors being category 6 - lecture (47.5%), category 9 - student statements (15.0%), and category 5 - teacher directions (10.7%). The rest of the period focused on student interaction with students observing the spectra of various light sources at the individual lab stations.

The third day, Teacher A gave his students brief instructions on how to complete Activity 4 (a concept introduction), had his students work in groups of two on a lap top computer in the physics classroom, and assigned Activity 5 (an application) as homework. After observing the entire class, the observation focused on two students working on the *Gas Lamp Spectroscopy* and *Energy Band Creator* computer programs as they completed Activity 4. Table 4-6 reveals that the first twenty minutes of this class emphasized student interaction (Student/Teacher ratio of 3.67) with a majority of the observed behaviors being category 13 - student interaction (30.8%) and category 12 - student activity (29.0%).

Teacher A and his entire class on the fourth day had a round table discussion of the results of the first five activities (excluding Activity 4). Table 4-6 shows that the emphasis of the first 20 minutes was on teacher interaction (Student/Teacher ratio of .55) with the majority of the observed classroom behaviors being category 6 - teacher lecture (37.0%), category 9 - student statements (28.8%), and category 4 - teacher questions (14.5%).

During the fifth day Teacher A introduced the concept of potential energy diagrams to the entire class by using dynamics carts and tracks and magnets – an approach used in *Potential Energy Diagrams* (Dimitrova, Rebello, & Zollman, 1996). The instructor had asked for and was given a draft of this unit prior to the field test. The instructor also used a gravitational analogy of stability to explain energy levels (Golab-Meyer, 1991).

On the same day, the instructor also asked his students to determine the peak wavelength of various LEDs and to use the cut-off voltage for each LED obtained from their graphs made in Activity 1 to determine Planck's constant (Activity 10) for homework. Table 4-6 reflects that the emphasis of the first twenty minutes was on teacher interaction (Student/Teacher ratio of .31) and that the majority of the observed classroom behaviors were category 6 - teacher lecture (44.9%), category 9 - student statements (16.2%), and category 8 - teacher demonstrations (14.5%).

Teacher A began the sixth day by reviewing with the entire class the concepts found in Activities 6 and 8 (both concept introductions) by demonstrating how the *Energy Band Creator* and *Semiconductor Device Simulator* computer programs illustrate respectively the allowed energies for multiple atoms and how an LED operates within the context of energy bands and gaps. Both the instructor and students noted that the potential energy diagrams for each end of a “solid” should be slight higher than the potential energy diagrams inside to represent that, although any electron in a solid’s conduction band is free to move around in the solid, it is still bound to the solid. Teacher A also demonstrated how three LEDs can be connected in series and in parallel (Activity 7 - an application). Table 4-6 shows that the emphasis of the first twenty minutes of this class was on teacher interaction (Student/Teacher ratio of .30) and that the majority of the observed classroom behaviors were category 6 - teacher lecture (51.7%), category 9 - student statements (18.0%), and category 8 - teacher demonstrations (12.4%).

On day 7, Teacher A reviewed Activity 8 with the entire class and demonstrated both *LED Spectroscopy* and *Semiconductor Device Simulator* computer programs. Table 4-6 reveals the emphasis for the first 20 minutes of this class was on teacher interaction (Student/Teacher ratio of .36) and that the majority of the observed classroom behaviors were category 6 - teacher lecture (43.3%), category 10 - student statements (21.0%), category 4 - teacher questions (13.7%), and category 8 - teacher demonstration (9.9%).

The last day of the field test was devoted to completing *Solids & Light* and reviewing for the exam that would be given to the students on the following class period. Teacher A discussed with the entire class the energy representation of a solid material and student results of the Planck’s constant activity (Activity 10). Teacher A also had his students divide up into groups of two to discuss some of the concepts introduced in Activity 9 (an application). Table 4-6 shows the emphasis for the first 20 minutes of this class was on teacher interaction (Student/Teacher ratio of .45) and that the majority of the observed classroom behaviors were category 6 - teacher lecture (41.4%), category 10 - student statements (22.9%), and category 4 - teacher questions (12.9%).

Teacher A modified *Solids & Light* and used only those aspects of the materials that he felt were appropriate for his modern physics students and were consistent with his teaching style which includes the use of student investigations, lecture, and class discussions. He also felt that he did not have enough time to implement all 10 activities as recommended.

Table 4-7 summarizes the observed classroom behaviors of the concepts physics course taught by Teacher B at the public high school. On the first day of the field test Teacher B, unlike Teacher A, explained to the entire class why they were doing the *Solids & Light* activities and what they would be doing. Teacher B demonstrated to the students, with the help of the closed-circuit camera and TV monitors, the various components of the circuit apparatus and explained their various roles in the circuit. Table 4-7 shows the focus of the first 20 minutes of Activity 1 was on teacher interaction (Student/Teacher ratio of .04) and the majority of the observed behaviors were category 6 - teacher lecture (86.7%). As the instructor was reviewing the various components of the circuit apparatus, the students did not have any of the equipment at their desks. Many of the students appeared bored and expressed very little interest in the materials. Teacher B, unlike Teacher A, handed out the activity worksheets to the students on the same day they were to asked to complete them.

Teacher B on the second day gave the entire class instructions on how to connect the various components of the circuit used in the first activity. Teacher B, unlike Teacher A, had his students make the circuit connections themselves. The instructor provided his students a picture of the circuit apparatus to help them make the connections and data tables to record their measurements. Teacher B felt the materials were too open-ended for his students, and they did not provide adequate instructions. The instructor eliminated the aspect of the first activity that required students to make current vs. voltage graphs. During most of the field test, the students worked in groups of 3 to 4 except when working on the computer (in which case the group sizes varied from one student on a computer to 2 - 3 students). Table 4-7 shows that the emphasis for the first 20 minutes of this class was on teacher interaction (Student/Teacher ratio of .17) and the majority of the observed behaviors were category 6 - teacher lecture (69.0%) with some behaviors being category 4 - teacher questions (7.7%), category 12 - student activity (5.5%), and category 14 - non-functional behavior (5.15%). After the first twenty minutes, the student interaction with the materials and with each other increased significantly as the students made their circuit connections and completed the investigation. The students required a great deal of assistance in connecting the various components of the circuit and some assistance in taking measurements.

Table 4-7: Observed Conceptual Physics Classroom Behaviors (Teacher B)

Cat.	***Day 1*** **Act 1 (vt#6)**	***Day 2*** **Act 1 (live)**	***Day 3*** **Act 1-3 (live)**	***Day 4*** **Act1-3c (live)**	***Day 5*** **Act 4 (live)**	***Day 6*** **Act 4&6 (live)**	***Day 7*** **Act 4&6c (live)**	***Day 8*** **Act 7 (live)**	***Day 9*** **Act 7&9 (live)**
1	1.1	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.3
2	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0
3	0.45	1.85	9.6	2.8	6.1	2.7	5.1	2.5	8.0
4	2.75	7.7	17.0	6.9	12.9	7.0	11.2	5.7	17.9
5	1.1	0.75	1.5	2.5	2.4	4.3	1.8	0.0	6.0
6	86.7	69.0	45.2	79.1	56.2	46.1	49.3	34.4	34.3
7	0.45	0.0	0.0	0.0	3.8	0.4	0.4	0.0	0.8
8	2.75	1.5	3.3	3.1	1.8	2.7	2.2	0.0	10.9
9	2.3	4.4	23.0	5.3	12.9	7.8	9.4	5.75	17.4
10	0.2	1.2	0.0	0.0	0.9	7.4	0.0	5.3	1.6
11	0.0	0.0	0.0	0.0	0.0	0.0	0.4	2.05	0.0
12	0.2	5.5	0.0	0.0	0.0	9.4	8.7	18.0	2.5
13	0.9	2.95	0.0	0.0	0.0	0.0	0.0	23.8	0.0
14	1.1	5.15	0.4	0.3	1.5	12.2	11.5	2.5	0.3
Tally #	**443**	**272**	**270**	**320**	**340**	**256**	**276**	**244**	**385**
Student/ Teacher	**.04**	**.17**	**.30**	**.06**	**.16**	**.39**	**.26**	**1.29**	**.27**

Note: Numbers in Regular Font Are Percentages

The third day, Teacher B began with summarizing the results of Activity 1 by using current vs. voltage graphs that were made not by his conceptual physics students but by Teacher A's modern physics students. Teacher B then introduced Ohm's law (Activity 2) to the students and introduced what they would be doing in Activity 3. Teacher B demonstrated to the students how to use the spectroscope to observe the spectra of various light sources. Students were then instructed to observe the spectra of gas lamps. As a result of his students having some initial difficulty in using the spectroscopes, Teacher B had his students use novelty diffraction grating glasses to observe the general spectral patterns and then the spectroscopes to make measurements. Table 4-7 reveals the focus of the first 20 minutes of class was on teacher interaction (Student/Teacher ratio of .30) and that the majority of the observed behaviors were category 6 - teacher lecture (45.2%), category 9 - student statements (23.0%), and category 4 - teacher questions (17.0%).

To start day 4, Teacher B discussed the results of the first two activities with his students and again provided the entire class with instructions on how to complete Activity 3. The instructor also demonstrated to the entire class how to use the *Gas Lamp Spectroscopy* and *Energy Band Creator* computer programs in preparation for Activity 4. Table 4-7 shows that the emphasis of the first 20 minutes of class was on teacher interaction (Student/Teacher ratio of .06) with the majority of the observed behavior being category 6 - teacher lecture (79.1%). The student interaction with the materials and with each other increased significantly at the end of the class when the students observed the spectra of various light sources set-up at individual lab stations.

Teacher B, on the fifth day, reviewed with the entire class their results of completing Activity 3 and had his students work on Activity 4 in the computer lab. The conceptual physics class observed on this day, however, did not have access to the computer lab during the entire field test as a result of a scheduling conflict. As a result, for this class Teacher B was limited to demonstrating *Gas Lamp Spectroscopy* and *Energy Band Creator* using his classroom computer and the two video monitors. Students in general appeared bored during this class period. The instructor introduced his students to the potential energy diagram (Activity 4) and often used the gravitational analogy of a ball moving up and down a hill in describing the potential energy diagram and used the gravitational analogy of stability in describing energy levels (Golab-Meyer, 1991). Table 4-7 reveals that the focus on the first 20 minutes of class was again on teacher interaction (Student/Teacher ratio of .16) and the majority of the observed behaviors were category 6 - lecture (56.2%), category 4 - teacher questions (12.9%), and category 9 - student statements (12.9%).

Teacher B began the sixth day of the field test by taking his classes to the computer lab and assigned his students Activities 4 and 6 to do in class and Activity 5 as homework. During this observation one student was working on each computer. Table 4-7 shows that the emphasis on the first 20 minutes was on teacher interaction (Student/Teacher ratio of .39) and that the majority of the observed behaviors were category 6 - teacher lecture (46.1%), category 14 - non-functional behavior (12.2%), category 12 - student activity (9.4%), categories 4 and 10 - teacher and student questions (7.0% and 7.4% respectively), and category 9 - student statements (7.8%). The degree of non-functional behavior observed for the conceptual physics classes was much greater than the degree of the behavior observed for the modern physics classes at the boarding school. After the first 20 minutes of class, the student interaction increased as the students utilized the computer programs to answer the questions found in the activities.

On day 7, Teacher B reviewed with the entire class how to use a spectrometer and demonstrated how the *Energy Band Creator* computer program can show the differences between two types of atoms in terms of potential energy diagrams and energy levels (Activity 4). Teacher B then instructed the students on how to connect the LEDs to a circuit so that they could observe the spectra of LEDs. Table 4-7 reflects that the focus of the first 20 minutes of class was on teacher interaction (Student/Teacher ratio of .26) and that the majority of the observed behavior was category 6 - teacher lecture (49.3%). Table 4-7 also shows, that in addition to the observed behaviors of category 4 - teacher questions (11.2%), category 9 - student statements (9.4%), and category 12 - student activity (8.4%), category 14 - non-functional behavior (11.5%) was again observed for the second consecutive day. During the rest of the period, the student interaction with the materials increased when the instructor had his students move to the computer lab and use the *Energy Band Creator* computer program to illustrate the energy levels of multiple atoms (Activity 6).

Teacher B, at the beginning of class on the eighth day, gave the entire class instructions to do Activity 7 (an application). Teacher B, unlike Teacher A, gave his students the task to connect three LEDs in a circuit in such a way that all three LEDs would emit light (Activity 7). The students seemed to be very interested in doing this activity and in attempting to connect a bi-color LED to a circuit in such a way that it emitted two different colors of light at once. Table 4-7 reveals that the first 20 minutes of class, unlike on the previous classes, emphasized student interaction (Student/Teacher ratio of 1.29) and that the majority of the observed behaviors were category 6 - teacher lecture (34.4%), category 13 - student interaction (23.8%), and category 12 - student activity (18.0%). The rest of the class period focused on student interaction as the students connected circuits consisting of more than one LED and a bi-color LED.

During the last day of the field test, the conceptual physics students were able to complete Activity 7. Teacher B also demonstrated the *LED Spectroscopy* computer program, discussed Activity 9, and summarized what the students had learned in the last two weeks. Teacher B skipped Activities 8 and 10 and did not demonstrate *Semiconductor Device Simulator* computer program because he felt his students did not have the background to understand the concepts that were introduced in these activities and computer program. Table 4-7 shows that again the first 20 minutes of class focused on teacher interaction (Student/Teacher ratio of .27) and that the majority of the observed behaviors were category 6 - teacher lecture (34.3%), category 4 - teacher questions (17.9%), category 9 - student statements (17.4%), and category 8 - teacher demonstrations (10.9%).

Teacher B admitted that he was spending too much time lecturing but felt that to complete the activities in the two week period he had to resort to lecturing. As a result, he often felt frustrated and uncomfortable with this approach. Teacher B also was frustrated in that he couldn't get one of his conceptual physics classes in the computer lab and was restricted to demonstrating the computer programs to the entire class as a result of a scheduling conflict. Teacher B indicated that, if he had the time, he would give the students more time to explore the LEDs and to interact with the computer programs.

Teacher C's classroom behaviors in the accelerated junior physics course are summarized in Table 4-8. Like Teacher B, he gave both his accelerated junior physics and algebra-based physics students the worksheets on the same day the activity was to be completed and provided his students with data tables to record their data collected for Activity 1. Teacher C, unlike Teacher B, had his students make current vs. voltage graphs for the first activity. Teacher C began *Solids & Light* by giving his accelerated junior physics students a very brief introduction to the various light sources that would be used and guiding his students in connecting the various components of the circuit apparatus. The students for most of the field test worked in groups of 4 to 5 with the exception of when they worked on the computer (in which case students worked in groups ranging from 1 to 4 students). Table 4-8 shows that the first 20 minutes of this class focused on teacher interaction (Student/Teacher ratio of .10) and that the majority of the observed classroom behaviors were category 6 - teacher lecture (50.0%) and category 8 - teacher demonstration (24.7%).

On the second day, which was a double lab period, Teacher C gave his students instructions on how to measure the current and voltage of the LEDs and incandescent lamp by using the multimeters and had his students complete the first activity. Although the students did have some initial difficulties in connecting the circuit, students were eventually able to collect data that were used to make their graphs. Teacher C assigned his students Activity 2 as a homework assignment. Table 4-8 reveals that the focus of

Table 4-8: Observed Accelerated Junior Physics Classroom Behaviors (Teacher C)

Cat.	***Day 1*** **Act 1** **(vt#7)**	***Day 2*** **Act 1** **(live)**	***Day 3*** **Act 3** **(live)**	***Day 4*** **Act 4** **(live)**	***Day 5*** **Act 5** **(live)**	***Day 6*** **Act 6**	***Day 7*** **Act 7** **(live)**	***Day 8*** **Act 7-8**	***Day 9*** **Act 7-9** **(live)**
1	0.3	0.0	0.0	0.0	.65	No Data	0.0	No Data	0.0
2	0.0	0.0	0.0	0.0	0.0		0.3		0.0
3	0.9	0.85	3.1	1.4	0.0		1.6		1.6
4	7.9	7.1	9.3	3.2	1.35		5.35		0.0
5	3.5	25.8	11.1	.35	2.05		12.5		0.0
6	50.0	44.1	23.1	50.4	48.0		38.6		66.5
7	2.5	0.0	0.0	0.0	0.3		2.2		0.0
8	24.7	2.1	2.2	.35	1.35		2.2		1.1
9	7.4	5.45	9.35	6.3	2.0		2.8		0.0
10	0.6	.85	1.8	2.1	2.3		1.9		3.7
11	0.3	0.0	0.0	0.0	1.0		0.0		0.5
12	0.0	7.1	25.8	33.05	21.65		19.75		9.0
13	0.3	6.25	13.8	2.5	18.35		10.0		11.2
14	1.6	0.4	.45	.35	1.0		2.8		6.4
Tally	**316**	**240**	**225**	**284**	**306**		**319**		**188**
Student/ Teacher	**.10**	**.25**	**1.04**	**.79**	**.84**		**.55**		**.35**

Note: Numbers in Regular Font Are Percentages

the first 20 minutes of class was on teacher interaction (Student/Teacher ratio of .25) and that the majority of the observed behaviors were category 6 - teacher lecture (44.1%) and category 5 - teacher directions (25.8%). After the first twenty minutes, the student interaction with the materials and with each other increased significantly as the students connected their circuits and completed their investigation on the electrical properties of LEDs.

After the students completed Activities 1 and 2, Teacher C unlike Teachers A and B did not summarize or discuss the results of the students previous investigations. Instead Teacher C started the third day of class by immediately giving instructions to the entire class on how to use the spectroscope to observe the spectra of various light sources for Activity 3. Because Teachers B and C had to share materials and equipment, their classes took turns going to a large classroom that contained the individual lab stations with various light sources in which students could observe their spectra. The sharing of resources by both teachers required not only cooperation but also careful planning as a result of their class schedules overlapping and the fact that their classrooms were on different floors in the school. The accelerated physics students, like the conceptual physics students, had some initial difficulty in using the spectroscopes. As a result Teacher C had his students use a diffraction grating to observe the general spectral patterns and then had them use the spectroscope to take measurements. Table 4-8 shows that the focus of the first 20 minutes of class was slightly on student interaction (Student/Teacher ratio of 1.04) with the majority of classroom behaviors being distributed among category 12 - student activity (25.8 %), category 6 - teacher lecture (23.1%), category 13 - student interaction (13.8%), category 5 - teacher direction (11.3%), category 9 - student statements (9.35%), and category 4 - teacher questions (9.3%). The rest of period focused on student interaction as the student observed the spectra of various light sources.

On the fourth day, Teacher C's students were in the computer lab to use the *Spectroscopy* and *Energy Band Creator* computer programs and complete Activity 4. On a number of occasions, one of Teacher C's classes had to share the computer lab with one of Teacher B's classes. On these occasions (including this class), the number of students working on a computer increased from one student (when one class was using the lab) to 3 students. Before the students went to work on the computer programs, Teacher C provided some instructions and introduced the concept of potential energy diagram by reading aloud the first few pages of Activity 4. Table 4-8 shows that the emphasis of the first 20 minutes of the class was slightly on teacher interaction (Student/Teacher ratio of .79) and that the majority of the observed behaviors were category 6 - teacher lecture (50.4%) and category 12 - student activity (33.05%).

During the fifth class meeting, Teacher C guided his students through the general procedures of and had his students work in groups of 2 to 3 to complete the activity in the computer lab. Table 4-8 reveals that the focus of the first 20 minutes of class was slightly on teacher interaction (Student/Teacher ratio of .84) and that the majority of the observed behaviors were category 6 - teacher lecture (48.0%), category 12 - student activity (21.65%), and category 13 - student interaction (18.35%).

Although observation data could not be collected on the sixth day of the field test as a result of an observation scheduling conflict with another course, Teacher C did give his students instructions on how to complete Activity 6. The students, working in groups of three, were able to complete the computer aspects of Activity 6 during class. At the end of the class, Teacher C collected the first five activities but did not review what the students had learned in these activities.

The seventh day began with the students receiving instructions on how to finish up Activity 6 and start Activity 7. They observed the spectra of LEDs (Activity 6) and started on Activity 7. Because the students again had some difficulty in observing spectra, Teacher C demonstrated the use of the diffraction grating and spectroscope. Table 4-8 shows that the emphasis of the first 20 minutes of the class was on teacher interaction (Student/Teacher ratio of .55) and that the majority of the observed behaviors were category 6 - teacher lecture (38.6%), category 12 - student activity (19.75%), category 5 - teacher direction (12.5%), and category 13 - student interaction (10.0%).

Data could not be collected on the eighth day of the field test as a result of an observation scheduling conflict. During this double lab period the students were working in the classroom on Activity 7 which involved connecting various LEDs and a bi-color LED in a circuit. During this time Teacher C took one student from each student group (about 6 to 12 students) and briefly demonstrated the *Semiconductor Device Simulator* computer program on one computer in the classroom until all students were able to see the demonstration (Activity 8).

On the ninth day the accelerated junior physics students worked on completing Activities 7-9 with groups of 6 to 8 students spending about 10 to 15 minutes working on *Semiconductor Device Simulator* computer program at a time. Although only one computer was in the classroom to demonstrate the computer program, Teacher C allowed his students to go the computer lab to finish any of the other computer aspects of the previous activities. Even though the students were still finishing the activities and no review or discussion had occurred, Teacher C announced to his students that an exam would be given on the following day. As a result of the amount of work assigned to them in a short period of time, students were working in such a way that one student in a group would work on one activity and another student work on another activity. The students would then share their results with one another. Table 4-8 reveals that the focus of the first 20 minutes of class was on teacher interaction (Student/Teacher ratio of .35) and that the majority of the observed behaviors were category 6 - teacher lecture (66.5%) with some behaviors being category 13 - student interaction (11.2%) and category 12 - student activity (9.0%).

Teacher C also implemented *Solids & Light* in an algebra-based physics course. Table 4-9 summarizes the classroom behaviors observed for this course. He utilized the materials in this course in the same manner in which they were used in the accelerated junior physics course. On the first day of field test, the first 20 minutes of class emphasized teacher interaction (Student/Teacher ratio of .23) and the majority of the observed classroom behaviors were category 6 - teacher lecture (59.1%) as the instructor explained to the entire class how to connect the circuit. Some observed behaviors were category 12 - student activity (13.3%) as the students conducted their investigations on the electrical properties of LEDs. The focus on the first 20 minutes of class on the second day of Activity 1 was still on teacher interaction (Student/Teacher ratio of .60) and the majority of the classroom behaviors were category 6 - teacher lecture (25.4%) in explaining how to connect the multimeters to the circuit, category 5 - teacher directions (17.6%) on how to make measurements (17.6%), category 13 - student interaction (13.0%) and category 14 - non-functional behavior (11.4%) which was also observed in the conceptual physics classes.

Table 4-9: Observed Algebra-Based Physics Classroom Behaviors (Teacher C)

Cat.	***Day 1*** **Act 1 (vt#8)**	***Day 2*** **Act 1 (live)**	***Day 3*** **Act 1-3 (live)**	***Day 4*** **Act 4 (live)**	***Day 5*** **Act 5 (live)**	***Day 6*** **Act 6 (live)**	***Day 7*** **Act 6-7 (live)**	***Day 8*** **Act 7-8 (live)**	***Day 9*** **Act 7-8 (live)**
1	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.4
2	1.7	0.0	0.0	0.0	4.7	0.0	0.0	0.0	0.0
3	1.9	2.1	0.45	6.6	2.4	2.45	2.7	0.6	0.4
4	7.7	6.7	4.5	9.0	2.4	2.7	4.2	2.75	0.4
5	5.2	17.6	3.2	3.6	4.4	9.5	9.8	0.9	0.0
6	59.1	25.4	34.4	43.7	66.2	25.4	41.3	50.8	22.6
7	0.5	0.0	0.0	0.3	2.0	0.0	0.0	1.2	0.0
8	3.9	3.6	2.7	3.3	4.4	1.7	3.4	0.9	0.4
9	3.9	7.3	6.8	8.3	5.9	7.1	4.9	3.1	0.7
10	1.4	4.1	2.3	1.5	3.5	4.75	2.3	6.1	3.7
11	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.9	0.4
12	13.3	8.8	33.9	16.2	3.8	36.95	22.3	29.05	51.2
13	0.0	13.0	9.05	0.6	0.0	0.0	7.6	3.4	19.4
14	1.4	11.4	2.7	6.9	0.3	8.15	1.5	0.3	0.4
Tally	**362**	**193**	**221**	**334**	**340**	**295**	**264**	**327**	**273**
Student/ Teacher	**.23**	**.60**	**1.15**	**.40**	**.15**	**1.15**	**.60**	**.74**	**3.12**

Note: Numbers in Regular Font Are Percentages

Table 4-9 shows that the focus on the first 20 minutes of class on the third day was on student interaction (Student/Teacher ratio of 1.15) and that the majority of the observed behaviors were category 6 - teacher lecture (34.4%) as the instructor provided instructions on how to use the spectroscopes and diffraction gratings and category 12 - student activity (33.9%) as students observed the spectra of various gas lamps.

Table 4-9 also shows that the emphasis of the first 20 minutes of class for the fourth and fifth days was on teacher interaction (Student/Teacher ratios of .40 and .15 respectively). Table 4-9 reveals, however, that more student activity (category 12), teacher questions (category 4), and student statements (category 9) were observed for the fourth day than for the fifth day of the field test. The observed classroom behavior for the first 20 minutes of class on the sixth day, a double lab period, and seventh day of the field test were mainly category 12 - student activity (36.95% and 22.3% respectively) and category 6 - teacher lecture (25.4% and 41.3% respectively) which is represented by the respective Student/Teacher ratios of 1.15 and .60. The focus of the first 20 minutes of class on the eighth day was on teacher interaction (Student/Teacher ratio of .74) and the majority of observed behaviors were category 4 - teacher lecture (50.8%) and category 12 - student activity (29.05%). Table 4-9 reveals that the first 20 minutes of the last day of the field test (the day prior to the administration of the exam) focused on student interaction (Student/Teacher ratio of 3.12) which is also reflected by the majority of the observed behavior being category 12 - student activity (51.2%).

The modern physics class taught by Teacher D was observed only during a double lab period on the second day of the field test. Table 4-10 summarizes the observed classroom behaviors. Teacher D gave the entire class very brief instructions before the students (in groups of 3) carried out their investigation of the electrical properties of LEDs. The circuit apparatus used by the students to conduct the investigation consisted of materials that were a mismatch collection of alligator clip wires, breadboards, digital multimeters, and analog meters as a result of combining what materials the instructor had with the materials provided by the KSU Physics Education Research Group. The students did have some difficulty in constructing the circuit apparatus and making measurements. Table 4-10 shows that the emphasis of the first 20 minutes of the class was on student interaction (Student/Teacher ratio of 3.19) with the majority of the observed behavior being on category 13 - student interaction (35.9%), category 12 - student activity (20.8%), and category 6 - teacher lecture (19.6%). The observed behaviors for Teacher D’s modern physics class was somewhat similar to the classroom behaviors observed for Teacher A’s modern physics class for the first activity in terms of the degree of student interaction. (See Table 4-6.)

Table 4-10: Observed Modern Physics Classroom Behaviors (Teacher D)

Categories	***Day 2*** **Activity 1 (live)**
1	0.0
2	0.0
3	0.0
4	1.2
5	1.6
6	19.6
7	0.0
8	1.2
9	8.2
10	9.5
11	0.8
12	20.8
13	35.9
14	1.2
Total Tallies	**245**
Student/Teacher	**3.19**

Note: Numbers in Regular Font Are Percentages

In using the *Instrument for Analysis of Science Teaching* to categorize and analyze the observed classroom behavior for each class, the amount of time focused on teacher interaction was quite apparent. Many of the observed behaviors during the first 20 minutes of each class involved lecturing or providing instructions or directions to students so that they would be able to conduct the investigations (especially Activity 1). The objective of the *Solids & Light* materials was to create an activity-based environment that facilitated student interactions with one another, the materials, the computer programs, and the teacher. The data collected by the IAST seems to indicate that the majority of the first 20 minutes of class was crammed with providing too many directions and instructions and not enough time being spent on student investigations or student and teacher discussions. In analyzing the classroom behavior, however, the fact that only the first twenty minutes each class was used to categorize behavior must be emphasized and that in most cases significant student interaction with the materials and computer programs did occur during the remainder of the period. The IAST was used during the first twenty minutes of class to determine the amount of instruction and direction that was provided by the teacher in order for the students to begin each activity. As a result, the *Instrument for Analysis of Science Teaching* alone can only give a partial picture of how *Solids & Light* was being used in the classroom. The IAST, however, used in conjunction with the other data collection procedures and instruments (i.e. informal observations and interviews, and questionnaires), which will be discussed in more detail shortly, allows for a more complete picture of how the unit was being implemented as well as students and teachers reaction to these materials.

The videotaped recordings of the observed classroom behaviors for some of the activities was used to establish reliability of the original observer's (I) categorization. Table 4-11 compares the classroom behaviors categorized by Observer I with a second observer (II) who was trained in using the IAST instrument. Table 4-11 shows that with the exception of categories 12 and 13, the differences between the two observers' categorizations were small. Table 4-11 also shows that the Scott's coefficient (Π) for the first videotaped segment was below the reasonable level of performance of .85 with a value of .48.

Table 4-11: Reliability of the Categorization of Observed Classroom Behaviors (Videotape #1)

Category	**Observer I**	**Observer II**	**| Difference |**	**Average**	**Average^2**
1	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0
3	0.3	1.75	1.44	1.02	0.01
4	1.3	2.23	0.93	1.77	0.03
5	4.9	2.23	2.67	3.57	0.13
6	6.2	4.71	1.49	5.46	0.30
7	0.0	0.0	0.0	0.0	0.0
8	0.7	0.0	0.7	0.35	0.0
9	6.6	7.9	1.3	7.25	0.53
10	4.3	8.20	3.89	6.25	0.39
11	4.6	6.2	1.6	5.4	0.29
12	31.1	16.9	14.2	24.0	5.76
13	39.7	49.4	9.7	44.55	19.85
14	0.3	0.5	0.2	0.4	0.0
Totals	100%	100%	38.12%		27.28%
Tally #	**305**	**403**			
Student/Teacher	**6.44**	**8.12**			
P	**.48**				

Note: Numbers in Regular Font Are Percentages

Table 4-12 compares the classroom behaviors categorized for the videotaped segments #2 through #5 by Observer I with those categorized by Observer II along with the Scott coefficients for each segment. With the exception of the #4 videotaped segment (which has a Scott coefficient of .65), the Scott coefficients for the videotaped segments were in the range of .44 to .48 which are below the reasonable level of performance of a .85. However, with the exception of the #3 videotaped segment, the Student/Teacher ratios illustrated in Table 4-12 determined by both observers for each videotaped recording were very similar. Although the resulting Scott's coefficients are below reasonable levels of performance, the Student/Teacher ratios, which reflect the type of interaction that occurs in the first 20 minutes of class and indicate how *Solids & Light* was implemented, were similar.

Table 4-12: Reliability of the Categorization of Observed Classroom Behaviors (Videotapes #2 - 5)

Category	**Vt #2**		**Vt #3**		**Vt #4**		**Vt #5**	
	Obs I	**Obs II**	**Obs I**	**Obs II**	**Obs I**	**Obs II**	**Obs I**	**Obs II**
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	6.7	14.4	0.9	9.12	5.4	8.48	3.1	7.74
4	6.7	5.22	2.6	2.14	8.4	14.5	8.9	11.2
5	10.7	3.73	1.1	0.54	3.2	1.0	0.0	0.57
6	47.5	46.8	14.7	13.7	44.9	37.2	51.7	40.4
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	5.7	1.99	1.8	1.07	14.5	15.5	12.4	9.74
9	15.0	7.21	5.9	3.22	16.2	16.2	18	28.74
10	4.7	4.98	8.8	7.24	2.9	4.24	3.5	0.0
11	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0
12	2.7	9.45	29.0	40.7	4.3	0.75	0.0	0.0
13	0.0	2.99	30.8	21.2	0.0	0.0	1.1	0.0
14	0.3	3.23	1.5	1.07	0.2	2.13	1.3	1.65
Totals	100%	100%	100%	100%	100%	100%	100%	100%
Tally #	**299**	**402**	**455**	**373**	**441**	**401**	**451**	**349**
Student/ Teacher	**.29**	**.34**	**3.67**	**2.72**	**.31**	**.28**	**.30**	**.41**
P	**.44**		**.49**		**.65**		**.48**	

Note: Numbers in Regular Font Are Percentages

Table 4-13 compares the classroom behaviors categorized for the videotaped segments #6 through #8 by Observer I with those categorized by Observer II along with the Scott coefficients for each segment. All three videotaped segments were below the reasonable level of performance (.85) with videotaped segments #6 and #7 being well below the reasonable level of performance (.10 and -.07 respectively). However, the Student/Teacher ratios (.04 and .05) determined by each observer for the #6 video segment were similar. In addition, the Student/Teacher ratios determined by each observer for all three video segments reflected the focus of the observed classroom behavior being on teacher interaction with the difference being on the degree of teacher interaction.

Table 4-13: Reliability of the Categorization of Observed Classroom Behaviors

(Videotapes #6 - 8)

Category	**Vt #6**		**Vt #7**		**Vt #8**	
	Obs I	**Obs II**	**Obs I**	**Obs II**	**Obs I**	**Obs II**
1	1.1	0.0	0.3	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	1.7	0.0
3	0.45	0.8	0.9	0.6	1.9	3.23
4	2.75	1.3	7.9	5.2	7.7	1.74
5	1.1	0.0	3.5	0.0	5.2	9.95
6	86.7	91.9	50.0	79.0	59.1	56.0
7	0.45	0.0	2.5	0.9	0.5	0.0
8	2.75	0.5	24.7	12.2	3.9	0.25
9	2.3	0.5	7.4	1.5	3.9	2.49
10	0.2	0.0	0.6	0.3	1.4	0.5
11	0.0	0.0	0.3	0.0	0.0	0.5
12	0.2	3.7	0.0	0.0	13.3	22.6
13	0.9	0.8	O.3	0.0	0.0	0.0
14	1.1	0.5	1.6	0.3	1.4	2.74
Totals	100%	100%	100%	100%	100%	100%
Tally #	**443**	**383**	**316**	**329**	**362**	**402**
Student/ Teacher	**.04**	**.05**	**.10**	**.02**	**.23**	**.37**
P	**.10**		**-.07**		**.45**	

Note: Numbers in Regular Font Are Percentages

Table 4-14 compares the observed classroom behaviors categorized by both observers for all 8 videotaped segments collapsed into student and teacher interaction categories. The total percentages do not add to 100 because category 14 of the *Instrument for Analysis of Science Teaching* was not included in either the student or teacher interaction category. With the exception of the seventh videotaped segment, the Scott coefficients were more reasonable with values that range from .57 to .93 and the total percentages were very similar. Although most of these coefficients were below the reasonable level of performance of .85, the magnitudes of the coefficients may also reflect the difficulty of using the instrument to categorize classroom behavior from a videotape especially in situations in which more than one observable classroom behavior occurred or in situations when the students and/or teacher are interacting with more than one groups. Although the reliability could have been improved by providing both observers with more intensive training in using the IAST instrument, the Student/Teacher ratios determined by each observer and the Scott's coefficients for each videotaped segment (with the exception of videotape #7) were close enough to determine general agreement on the degree of student or teacher interaction observed for the first 20 minutes of class.

Table 4-14: Reliability of the Categorization of Observed Student/Teacher Behaviors (Videotapes #1 - 8)

Vt/Observer	**Student**	**Teacher**	**Total**	P
Vt #1/ I	86.3	13.4	99.7	**.78**
II	88.59	10.91	99.5	
Vt #2/ I	22.4	77.3	99.7	**.81**
II	24.63	72.14	96.77	
Vt #3/ I	77.4	21.1	98.5	**.73**
II	72.36	26.57	98.93	
Vt #4/ I	23.4	76.4	99.8	**.93**
II	21.19	76.68	97.87	
Vt #5/ I	22.6	76.1	98.7	**.69**
II	28.7	69.95	98.35	
Vt #6/ I	3.6	95.3	98.9	**.77**
II	5.0	94.5	99.5	
Vt #7/ I	8.6	89.8	98.4	**.40**
II	1.8	79.95	81.75	
Vt #8/ I	18.6	80	98.6	**.57**
II	26.09	71.17	97.26	

Note: Numbers in Regular Font Are Percentages

4.3 Student Attitudes Towards Solids & Light

Upon completion of *Solids & Light*, students were asked to rate their feelings about the instructional techniques, the potential energy diagram as a model for the atom, and the computer programs in terms of their usefulness or effectiveness in helping them understand the introduced concepts and make observations. Table 4-15 summarizes the student mean ratings for the non-computer aspects of *Solids & Light*.

Student ratings of the exploration aspect of *Solids & Light* across all courses were somewhat favorable with the lowest mean rating (3.08) given by the conceptual physics students and the highest mean rating (3.67) given by the accelerated junior physics students. A One-Way ANOVA, which was adjusted for unequal sample sizes and heterogeneity of variances, failed to reveal any significant difference between any two mean ratings of the exploration aspects across course levels. (See Table 4-15.)

Although the use of the potential energy diagram was rated as somewhat favorable by all students, Table 4-15 shows that the modern physics students rated the effectiveness of the potential energy diagram higher (3.94) than the rest of the students. A One-Way ANOVA, which did not fail the homogeneity of variance test, revealed the modern physics students mean rating of the potential energy diagram was significant higher than the student ratings from the other courses. This result should not be surprising since Teacher A discussed potential energy diagrams with more detail than the other teachers.

Table 4-15: Student Mean Ratings (and Standard Deviations) of the Solids & Light Non-Computer Aspects by Course

Strategy	**Conceptual Physics**	**Accelerated Physics**	**Algebra-based Physics**	**Modern Physics**
Exploration	**3.80 (.85)** **n = 66**	**3.67 (.52)** **n = 24**	**3.49 (.62)** **n = 37**	**3.38 (.89)** **n = 18**
PED	3.10[1] (.68) n = 66	3.38[1] (.64) n = 23	3.24[1] (.76) n = 34	3.94[1a] (.58) n = 17
Directions	**3.14[1](.88)** **n = 29**	**3.17 (.97)** **n = 21**	**3.59 (.87)** **n = 28**	**3.86[1a] (.36)** **n = 14**
Understanding	3.32[1](.95) n = 28	4.14[1a] (.96) n = 21	4.11[1a] (.74) n = 28	4.00[1a] (.65) n = 15
Recommendation	3.21 (.94) n = 29	2.79[1](1.17) n = 21	3.18 (.91) n = 28	3.80[1a] (.77) n = 15
Teacher:	*B@HS*	*C@HS*	*C@HS*	*A@BS*

1 = Least effective; 5 = most effective

Bold represents means that failed Test for Homogeneity of Variances at .05 level.

[1] Denotes significantly different on adjusted or unadjusted One-Way ANOVA and post-hoc comparison test at $p < .05$.

[1a] Denotes significantly larger value(s).

In terms of the effectiveness of *Solids & Light* providing adequate directions, Table 4-15 reveals that the modern physics students mean rating on this aspect was significantly higher (3.86) and more homogeneous than the concepts physics students mean rating (3.14). Table 4-15 also reveals that the algebra-based physics students rated the effectiveness of the unit in providing adequate directions as high as the modern physics students ratings but the algebra-based physics ratings were more heterogeneous.

Table 4-15 shows that the accelerated physics, algebra-based physics, and modern physics students rated the effectiveness of the materials in developing understanding significantly higher (4.14, 4.11, and 4.00 respectively) than the conceptual physics students (3.32). The following comments made by some of the conceptual physics students indicates their frustration in not being able to understand some of the concepts: “This unit was very difficult for me to understand because we just jumped into this complicated field.” and “I really didn’t understand that much about LEDs and gas lamps during these activities. I think it was the way the unit was presented to me.”

Table 4-15 also shows that the modern physics students were more likely to recommend the unit to a friend than the accelerated junior physics students. Table 4-15 reveals that modern physics student mean rating was significantly higher (3.80) than the accelerated junior physics student mean rating (2.79). The mean rating of 2.79 is the lowest student mean rating of all the non-computer aspects of *Solids & Light*. The following comments made by the modern physics students reflect their enthusiasm for the unit: “Not a bad overall plan to progress from observation to a model of how atoms emit light.”, “A good consummation of the work done in previous sections.”, “The Aha! experience of understanding how LEDs work was somewhat delayed but it was there.”, and “I now know how atoms behave the way they do and also why.”.

To determine whether students ratings of recommending the unit were influenced by their attitudes toward physics, an ANCOVA with an independent variable of course level, a covariate of SMATP score, and a dependent measure of student ratings of recommending the unit was calculated. Table 4-16, which summarizes the results of the ANCOVA, reveals that students recommendation ratings were not significantly related to their attitudes toward physics, the course main effect was not significant, and the course and SMATP scores explain a significant amount of variance. As a result of no significant relationship existing between students recommendation ratings and their attitudes toward physics, the results of the One-Way ANOVA found in Table 4-15 should be used to show how the level of physics course affects student recommendation scores so that statistical power is not lost.

Table 4-16: ANCOVA Summary for Student Ratings of Recommending Solids & Light

Covariate (SMATP)	Main Effects (Course)	Explained (SMATP + Course)
F (1, 76) = 1.09	F (3, 76) = 2.65	F (4, 76) = 2.88* (R^2 = .0087)

* $p < .05$

Table 4-17 summarizes the results of comparing female and male student ratings of the non-computer aspects of *Solids & Light*. T-tests for independent samples were conducted to determine if student's gender had any affect on student ratings of these non-computer aspects. The results of these t-tests reveal that gender did not have any affect on any of the non-computer aspects of *Solids & Light*. The female and male students ratings of the non-computer aspects of the unit were very similar.

Table 4-17: Male and Female Student Mean Ratings (and Standard Deviations) of the Solids & Light Non-Computer Aspects

Strategy	Female	Male
Exploration	3.32 (.72) n = 68	3.32 (.85) n = 77
PED	3.18 (.74) n = 66	3.38 (.71) n = 74
Directions	3.27 (.94) n = 42	3.49 (.81) n = 50
Understanding	3.79 (.89) n = 43	3.92 (.93) n = 49
Recommendation	3.21 (.94) n = 43	3.19 (1.05) n =50

Table 4-18 summarizes student mean ratings by course of the computer programs utilized in *Solids & Light* as well as a total computer rating that was calculated. One more course was added to take into account the conceptual physics class in which the students did not interact with the computer programs. One-Way ANOVA's were calculated to determine if significant differences existed between any two student mean ratings. The variances for all means across course levels in each computer category were homogeneous and as a result the One-Way ANOVA's did not have to be adjusted for heterogeneous variances.

The modern physics students, algebra-based physics students, and accelerated junior physics students rated the *Gas Lamp Spectroscopy* computer program significantly higher (4.06, 3.76, 3.54

respectively) than the conceptual physics students who did not interact with the computer program themselves (2.73). Table 4-18 also shows that the modern physics students and algebra-based physics students rated *Spectroscopy* significantly higher than the conceptual physics students who did interact with the computer program (2.89).

Table 4-18: Student Mean Ratings (and Standard Deviations) of the Solids & Light Computer Programs by Course

Computer Program	**Conceptual Physics**	**Conceptual Physics w/o Comp**	**Accelerated Physics**	**Algebra-based Physics**	**Modern Physics**
Spectroscopy	2.89^{2} (1.02) n = 44	2.73^{1} (.83) n = 22	3.54^{1a} (.75) n = 23	$3.76^{1a,2a}$ (.89) n = 34	$4.06^{1a,2a}$ (.75) n = 17
EB Creator	3.41 (.86) n = 45	2.95^{1} (.96) n = 22	3.44 (.97) n = 24	3.55 (.85) n = 37	4.04^{1a} (.72) n = 18
SD Simulator	3.33 (.73) n = 21	2.88 (.64) n = 8	3.57 (.98) n = 21	3.36 (.95) n = 28	3.80 (1.01) n = 15
Total Comp	3.24^{2} (.72) n = 33	2.86^{1} (.70) n = 22	3.51^{1a} (.70) n = 24	3.58^{1a} (.69) n = 37	$3.97^{1a,2a}$ (.71) n = 18
Teacher:	*B@HS*	*B@HS*	*C@HS*	*C@HS*	*A@BS*

[1,2] Denotes significantly different on adjusted and unadjusted One-Way ANOVA and post-hoc comparison test at $p < .05$.

[1a, 2a] Denotes significantly larger value(s).

The modern physics students also rated the *Energy Band Creator* computer program significantly higher (4.04) than the conceptual physics students who did not have access to computers (2.95). Student mean ratings for the *Energy Band Creator* from the other courses were in between 3.41 (conceptual physics students with computers) to 3.55 (algebra-based students).

Although modern physics students rated the *Semiconductor Device Simulator* computer program higher (3.80) than the other students, the modern physics student mean rating for the program was not significantly higher the other students' ratings. Table 4-18 shows that again the conceptual physics students who did not have access to computers rated *Semiconductor Device Simulator* the lowest with a mean rating of 2.88.

When combining students ratings into a total computer rating, Table 4-18 reveals that modern physics students, algebra-based physics students, and accelerated physics rated the computer aspect of

Solids & Light significantly higher (3.97, 3.58, and 3.51 respectively) than the conceptual physics students who did not have access to computers (2.86). Table 4-18 also shows that modern physics students rated the computer aspect of the unit significantly higher than the conceptual physics students who used computers (3.24).

To determine whether students ratings of the *Solids & Light* computer programs were influenced by their comfort/anxiety levels in using computers, an ANCOVA with an independent variable of course level, a covariate of ATCT score, and a dependent measure of student total computer rating was calculated. Table 4-19, which summarizes the results of the ANCOVA, reveals that students total computer ratings were not significantly related to student comfort levels in using computers, the course main effect was significant, and the course and ATCT scores explain a significant amount of variance. As a result of no significant relationship existing between students total computer ratings and their attitudes toward computers, the results of the One-Way ANOVA found in Table 4-18 should be used to summarize how the level of physics course affects student total computer ratings so that no statistical power is lost.

Table 4-19: ANCOVA Summary for Student Total Computer Ratings

Covariate (ATCT)	Main Effects (Course)	Explained (ATCT + Course)
F (1, 108) = .304	F (4, 108) = 5.98*	F (5, 108) = 4.87* ($R^2 = .008^2$)

* p < .05

The results of comparing female and male student ratings of the *Solids & Light* computer programs are summarized in Table 4-20. T-tests for independent samples were conducted to determine if student's gender had any affect on student ratings of the computer programs. As was the case for the non-computer aspects of *Solids & Light*, the results of these t-tests reveal that gender did not have any affect on student ratings of the *Solids & Light* computer programs. The female and male students ratings of the computer programs were very similar.

Table 4-20: Male and Female Student Mean Ratings (and Standard Deviations) of the Solids & Light Computer Programs

Strategy	Female	Male
Gas Lamp Spectroscopy	3.35 (1.00) n = 66	3.30 (1.01) n = 74
Energy Band Creator	3.40 (.76) n = 69	3.52 (1.03) n = 77
Semiconductor Device Simulator	3.28 (.96) n = 43	3.56 (.87) n = 50
Computer Total	3.35 (.73) n = 65	3.47 (.80) n = 69

Table 4-21 summarizes student mean ratings of each computer program by course. One-Way ANOVA's were calculated for each course to determine if student mean ratings for any two of the three computer programs were significantly different. Although none of these statistical tests were significant at the .05 level, the resulting means were quite interesting. For example, the conceptual physics students (those who interacted with the computer programs and those that didn't) rated the effectiveness of the *Energy Band Creator* and the *Semiconductor Device Simulator* computer programs higher than the *Gas Lamp Spectroscopy* computer program. The accelerated junior physics students rated the effectiveness of *Spectroscopy* (3.54) and *Semiconductor Device Simulator* (3.57) higher than *Energy Band Creator* (3.44). The algebra-based physics students rated *Spectroscopy* (3.76) higher than the other two programs. The modern physics students rated the effectiveness of *Spectroscopy* (4.06) and *Energy Band Creator* (4.04) higher than *Semiconductor Device Simulator* (3.80). The expected result would be that the students (especially the conceptual physics students) would rate the effectiveness of *Spectroscopy* higher than the other two programs because of the level of abstraction associated with *Energy Band Creator* and *Semiconductor Device Simulator* computer programs. This result was the case with the exception of both sets of conceptual physics students. The exceptions are even more surprising when one takes into consideration that the conceptual physics students (especially the students who did not interact with the computer programs) had very limited access to *Semiconductor Device Simulator.* The conceptual physics students exposure to *Semiconductor Device Simulator* was limited to a very short demonstration given by Teacher B.

Table 4-21: Student Mean Ratings (and Standard Deviations) by Computer Program

Course	**Teacher**	***Gas Lamp Spectroscopy***	***Energy Band Creator***	***Semiconductor Device Simulator***
Conceptual Physics	B @HS	2.89 (1.02) n = 44	3.41(.86) n = 45	3.33 (.73) n = 21
Conceptual Physics w/o Comp	B @HS	2.73 (.83) n = 22	2.95 (.96) n = 22	2.88 (.64) n = 8
Accelerated Physics	C @HS	3.54 (.75) n = 23	3.44 (.97) n = 24	3.57 (.98) n = 21
Algebra-based Physics	C @HS	3.76 (.89) n = 34	3.55 (.85) n = 37	3.36 (.95) n = 28
Modern Physics	A @HS	4. 06 (.75) n = 17	4.04 (.72) n = 18	3.80 (1.01) n = 15

In addition to rating the certain aspects of the *Solids & Light* materials, students were also asked to respond to a number of open-ended questions. For example, one question asked the students to summarize what they had learned. The modern physics students taught by Teacher A indicated that they learned about spectra and light (with specific references to spectral differences between gas lamps, LEDs, and incandescent lamps as well as the relationship between energy levels and spectra), and LEDs, incandescent lamps, and gas lamps (with specific references to electrical properties, LEDs do not act like incandescent lamps and do not obey Ohm's law, and how an LED works at the atomic level).

The conceptual physics students taught by Teacher B also indicated that they, too, learned about spectra and light and the various light sources with specific references to other aspects. The conceptual physics students reported that they learned about:

- spectra and light (with references to how to use a spectroscope, relationship between color and energy of light, and that LEDs and gas lamps only emit certain patterns of light),
- LEDs (including bi-color LEDs), incandescent lamps, and gas lamps (with references to how the various lights work, the electrical differences between these light sources),
- how to connect different light sources in a circuit,
- how to measure currents and voltages, and
- how to use new computer programs.

The conceptual physics student responses, unlike the modern physics student responses, focused more on particular skills rather than concepts that they learned. Some conceptual physics students indicated that they didn't learn anything during the field test.

As a result of completing *Solids & Light,* the accelerated junior physics students taught by Teacher C reported that they also learned about spectra and light (with specific references to how LEDs can replace an incandescent lamp and light emission is due to energy level differences), and LEDs (including bi-color LEDs), incandescent lamps, and gas lamps (with specific references to their electrical properties and differences). The algebra-based physics students also taught by Teacher C indicated that they learned about:

- spectra and light (with specific references to the relationship between color and energy, how to use a spectroscope, and that LEDs can replace the incandescent lamp),
- LEDs (including bi-color LEDs), incandescent lamps, and gas lamps (with specific references to their electrical properties and differences),
- how to put together a circuit that includes a light source, and
- energy levels in solids and gases.

Teacher B's and C's students all mentioned that they learned how to connect a circuit with a light source which was a major emphasis for the first couple of days of the field test. Teacher A's students made no mention of the circuit as a result of using a pre-made circuit apparatus (a "black box").

When the modern physics students were asked what aspects of the *Solids & Light* they considered to be the most fun or interesting, they mentioned observing the spectra of various light sources with a spectroscope and interacting with the computer programs, especially *Gas Lamp Spectroscopy*. The following comments made by these students reflect their attitudes toward the computer aspects of the unit: "This is the first time I used a computer so much during a lab and I found it to be very interesting.", "The computer simulations were much more interesting than reading explanations or looking at diagrams in books.", and "The hand out and *Gas Lamp Spectroscopy* that led us through the gas lamp activity (Activity 4) was helpful. I wouldn't have been able to understand LEDs without it.". One student considered the Planck's constant activity (Activity 10) to be excellent. He or she, however, felt more explanations and background would have been helpful.

The conceptual physics students who had access to the computer programs also considered observing the spectra, interacting with the computer programs, trying to get the LEDs to light, and connecting light sources to the circuit board to be the most interesting or most fun aspects of *Solids & Light*. The student comment, "The 'funnest' thing was going into the lab and working on the computers trying to figure it out [the relationship between energy levels and spectra lines] and putting the different gas lamps in different places.", reflects some of the students feelings toward the computer programs. According to their instructor (Teacher B), the computer programs passed the "video game" test in that they got the students attention and interest. The conceptual physics students who did not have access to the computer programs also considered observing the spectra with spectroscopes, trying to the LEDs to light, and playing with lights to be the most interesting aspects of *Solids & Light*. These students did not mention anything about the computer programs.

The accelerated junior physics and algebra-based physics students also considered using the computer software (especially *Gas Lamp Spectroscopy*), observing the spectra with spectroscopes, the hands-on activities, and connecting LEDs to the breadboards, and when they were able to get the LEDs and incandescent lamp to emit light to be the most interesting aspects of *Solids & Light*. The following comments reflect the accelerated physics students attitudes towards these aspects: "The activities were fun for the most part because they were not all lectures and question-answer format.", "Using the computer for learning is a very good idea.", " I enjoyed working on the computer programs because it was a break from working on older computers.", "I loved working with the LEDs and the breadboards. I liked being able to connect the bi-color LED and seeing how it changed from one color to another.", and "It felt good when I could get the light source to light as a result of connecting my own circuit.".

The following comments made by the algebra-based physics students reflect their attitudes toward *Solids & Light* in general: "The unit needs to be taught with more information on how to connect circuits and by someone with more expertise on the subject.", "It's cool to learn new and different things. When I understood it was very rewarding.", and "The most fun was experimenting with lights and the satisfaction you felt when you finally got them to light.". Some of these students also commented that they liked working in small groups during the field test because it allowed them to reinforce and clarify understanding of concepts through discussions with other students. The following comments reflect some of the algebra-based physics students attitudes toward the computer programs: "I had a lot of fun with the computer programs and enjoyed learning about LEDs.", "The computer programs were the best part of this experiment in that they were visual and focused on one concept at a time.", and "I wish we could have spent more time on certain activities and the computer programs.". Some algebra-based physics students, however, thought the computer programs were difficult to use, that the computer programs were not necessary, and that the teacher could have explained the concepts more effectively.

When asked what they considered to be least fun aspects of *Solids & Light*, the modern physics students considered answering the questions and using the spectroscope to observe spectra to be the least fun. Some of the comments made by the students indicate some revision of the unit is necessary. For example, "Some of the activities could have been explained in greater detail.", "There needs to be more of an introduction of the unit. We started something completely different from what we had been doing previously and an introduction would have helped us switch gears a little more smoothly.", and "A lecture on atomic structure would allow for a more effective investigation into the actual working of an LED". One student felt that it was assumed that the questions in the activities would lead you along a "path'' that comes to the right answer but she sometimes felt lost along the way.

All the conceptual physics students considered the worksheets themselves to be an endless source of paperwork and the questions to be redundant and somewhat confusing. As a result, these students considered the worksheets and questions to be the least fun aspect of the unit. In addition, some of the conceptual physics students who did not have access to computers indicated that they were struggling to connect the circuit and did not consider it fun. Some conceptual physics students felt that *Solids & Light* was too difficult to understand and complicated. Other students indicated that they had fun doing the activities. One student commented that there needed to be an introductory lesson on the subject before the students jumped right into the activities.

The accelerated junior physics and algebra physics students considered the questions to be redundant, felt the materials, procedures, and concepts being introduced were somewhat confusing, and felt the activity worksheets and questions were the least fun aspects of *Solids & Light*. One student commented that he or she really didn't understand the concepts being introduced at all and after completing *Solids & Light* still didn't know what quantum mechanics was about. Although some students complained that too much work was crammed into too little time and that they didn't really understand the what was being introduced, most students indicated they felt the unit was interesting and did try to learn and absorb as much as possible. Most students indicated that they needed more time to review and reflect on what they learned previously to help them understand. They also felt that the instructor should have given more specific instructions at a slower pace and on an individual level especially since the activities were very much different than the typical way the class was taught. The students indicated that Teacher C traditionally assigned them a few homework problems but nothing like what they had been doing during the field test. Most students were also frustrated with not being able to finish a particular activity and being rushed to complete the activities. The following student comment seems to summarize these students frustrations, "Sometimes the purpose of what we were doing or trying to do got confused and it seemed like we were just doing it to do it without understanding why.".

Students seemed to indicate that they learned the most from the aspect of *Solids & Light* that they considered to be the most fun or interesting. This result is consistent with the feedback collected from students in previous field tests of *Solids & Light* (Escalada, Rebello, & Zollman, 1997).

4.4 Instructor Attitudes Toward Solids & Light

Upon completion of *Solids & Light*, the teachers were also asked to rate how they felt about the instructional techniques, the potential energy diagram as a model for the atom, and the computer programs in terms of their usefulness or effectiveness in helping their students understand the introduced concepts and make observations. Table 4-22 summarizes the instructor mean ratings for these strategies associated with *Solids & Light*. Data were not collected from Teacher B who taught the conceptual physics and Teacher D who taught modern physics at the public high school. However, data were collected from Teacher E who taught a honors physics course for seniors.

Teacher E who just covered a unit on Ohm's law before the field test rated the explorations on the electrical properties of LEDs higher (3.78) than Teacher A (3.22) and Teacher C (2.56). The teachers' ratings of the spectral explorations were very similar with a rating of about 3.70. Teacher C rated the effectiveness of the questions higher (3.75) than Teacher E (3.00) and Teacher A (2.63). Teachers A's and E's ratings on the effectiveness of the explanations were similar (3.33) while Teacher C gave this category a low rating (2.00). Teachers A and E rated the effectiveness of the potential energy diagram (without the use of the computer program) very low (1.50 and 1.00 respectively). While both Teachers A and C gave the *Gas Lamp Spectroscopy* computer program very high marks (4.00 and 5.00 respectively), Teacher E rated the program with the lowest score possible (1.00). The low rating by Teacher E could be the result of the teacher noticing that the spectral data in the software did not match with her and her student observations. After this comment was made by Teacher E (who had a background in spectroscopy research), the spectral data were reviewed by members of the KSU Physics Education Research Group. Upon confirmation of the problem, corrections were made to the *Gas Lamp Spectroscopy* computer program. Unfortunately, the modifications could not be made until after the field tests were complete.

Table 4-22: Instructor Mean Ratings (and Standard Deviations) of Solids & Light Instructional Strategies

Strategy	**Teacher A@BS Modern Physics**	**Teacher C@HS Algebra-based Physics & Accelerated Physics**	**Teacher E@PHS Honors Physics**
LED Electrical Properties	3.22 (.97)	2.56 (1.51)	3.78 (.57)
Spectral Properties	3.75 (.50)	3.75 (.96)	3.63 (.48)
Questions	2.63 (.48)	3.75 (.50)	3.00 (.50)
Explanation	3.33 (.58)	2.00 (1.40)	3.33 (.58)
Potential Energy Diagrams w/o Computer	1.50	3.00	1.00
Spectroscopy	4.00	5.00	1.00
Energy Band Creator	2.33 (.58)	3.33 (2.08)	2.40 (1.26)
Semiconductor Device Simulator	4.00	5.00	3.00

The teachers ratings of *Energy Band Creator* fall under the category of fair with Teacher C giving the program the highest ratings (3.33). All three teachers gave the *Semiconductor Device Simulator* program somewhat favorable ratings with Teacher A giving the program a rating of 5.00.

The *Solids & Light Instructor Questionnaires* also contained a number of open-ended questions. For example, teachers were asked to identify the important concepts that their students had learned. The teacher responses to this question for the most part were similar to the answers that their students gave on what they learned from the unit. Teacher A indicated that his modern physics students learned how to view and interpret spectra, how to relate spectra to potential energy diagrams, how nearby atoms effect each other, and about energy gaps and bands (conduction and valence). Teacher C indicated that his accelerated junior physics and algebra-based physics students learned how LEDs and incandescent lamps are different, electricity flows in a closed loop, LED and gas lamp spectra are different and why they are different, why a semiconductor conducts in only one direction, and energy levels and transitions. Teacher E indicated that her honors physics students learned how energy level transitions have some relationship with observed spectra, various electrical devices have different electrical properties, and splitting of levels and broadening of spectra result when atoms come close together. Responses to the question were not collected from Teachers B and D.

All five teachers indicated that *Solids & Light* was appropriate for their students with some exceptions but felt the materials needed to present more detailed information about potential energy diagrams and less redundant and more clear questions. All the teachers attempted to provide their students with concrete examples of the potential energy diagram and energy levels by utilizing gravitational analogies. Teacher B had concerns about introducing the concept of energy levels to his conceptual physics students due the abstract nature of the concept. Teachers B, C, and D indicated that their students lacked the skills in setting up the circuit and using multimeters to make voltage and current measurements. Teacher B also felt his students did not have adequate understanding of Ohm’s law to appreciate the electrical differences between the incandescent lamp and LED. Teacher B also commented that his students were capable of learning the materials but wasn’t sure his students were willing to make the effort especially the week before Christmas break when the field test took place.

Teacher B liked the open-ended nature of the activities in that students must rely on their own investigations as well as the written hand-outs to answer questions. Teacher B suggested that the written activities should be designed in such a way to separate the text, instructions, or questions so that teachers could focus on and discuss certain sections rather than having the students take the time to read all sections. Teacher B indicated that the problem with the written activities was that his conceptual physics students were in the habit of being assigned worksheets. As a result, he felt his students were considering the written activities as worksheets and only answering the questions and doing what was asked but not really reading and following the directions.

Teacher D also commented that his modern physics students weren't reading and following the directions and were immediately going to the investigations. He had to tell them to read specific details which he felt took more time than necessary. After the first couple of days of the field test, Teacher D identified a conflict between how he was teaching the course (very open-ended, little teacher instruction) and how the materials were presented. Teachers C, D, and E initially felt that the materials were self-standing and that their students could complete the activities on their own with very little instruction from them. Problems arose as a result of this type of thinking. For example after taking electrical measurements for the incandescent lamp, Teacher D's students then took measurements for the LEDs. As a result of students observing differences in terms of electrical properties between the incandescent lamps and LEDs, his students thought the circuit containing the LEDs was not connected correctly. The modern physics students would then precede to disconnect the circuit and made changes to the apparatus and repeated their measurements. At this point, Teacher D changed his instructional approach and provided his students more detailed instructions as they carried out their investigations. Teacher E also changed her instructional approach during the field test.

Although the teachers had no prior knowledge of solid state physics, the teachers felt comfortable with *Solids & Light* with the exception of the concepts introduced in Activity 8 (i.e. fermi levels, acceptors, and donors) which were not really discussed in detail but were illustrated in the *Semiconductor Device Simulator* computer program. Teacher C didn't feel comfortable with the concept of potential energy diagrams. All five teachers felt these concepts, especially potential energy diagrams, should have been described and defined in more detail in the instructor's manual. Teacher B felt that students and teachers were expected to buy into the concept of a potential energy diagram on faith by the way it was presented in the unit.

With respect to the instructor's manual, all teachers indicated that a more comprehensive, "how to teach" manual with solutions was needed rather than the current instructor's manual which they considered to be more of a "users" guide. The teachers commented that teachers who haven't taught quantum mechanics in the past also need materials to help them understand what they are teaching to enable them to answer student questions that they are encountering as they field test *Solids & Light*. Teacher A indicated that the manual should be easy to access in the planning stage of the implementation rather than having separate manuals (i.e. instructor's manual and computer manuals). Teacher E suggested a homework packet with discussion guide should also be provided with the instructor's manual. Teacher A suggested that the manual should include a table that contains a list of semi-conductors, energy gaps, and the resulting energy of light emitted so that students could compare the LEDs they designed with the *Semiconductor Device Simulator* computer program to the values indicated on the table. Teacher B recommended that the manual contain sample electrical and spectral data so that teachers could deal with the possibility that their students may not be able to make the necessary observations that would allow them to complete *Solids & Light*.

The teachers felt that the instructional and technical assistance provided during the field test provided answers to questions that they had about potential energy diagrams, band gaps, and the relationship between energy bands and spectra that were not provided in the instructor's manual. Teacher E felt the manual was not useful as a result of her having to spend a few hours on the phone to obtain instructional and technical assistance.

The two teachers who integrated computers in their modern physics course, Teachers A and D, suggested that they would have liked to have the written materials on computer disk so they could personalize the hand-outs and be able to separate homework and in-class activities. Both Teachers A and B suggested that each activity end with a short follow up activity or homework question to allow students to synthesize what they had learned. Both Teachers B and C recommended replacing the incandescent lamp that was used with one that will more effectively illustrate how light intensity varies with resistance. The teachers felt the incandescent lamp used in the circuit appeared to be either on or off which gives the wrong impression that the incandescent lamps behave like an LED.

When asked if they would recommend *Solids & Light*, all five teachers indicated that they would with revision and if the teacher had the time because the activities took too long. Teacher C commented that he would recommend the unit because the materials were hands-on, experimental, computer visual, and conceptual. He mentioned that his students were motivated by the materials because they considered the investigations to be like puzzles which they had to figure out. Teachers B and C were enthusiastic about the materials because they noticed that many of their students who did performed well in their classes in the past were coming in during lunch and after school to complete the activities and that some of their students were getting ideas on what they could for future science fair projects. Both Teachers B and C were excited about the materials and planned on making investments on breadboards, spectroscopes, and multimeters so that *Solids & Light* could be used in the future.

Although his students did not appear comfortable in learning about energy levels without knowing how they are formed, Teacher A indicated that he would incorporate *Solids & Light* in his modern physics course after the topics of relativity and the photoelectric effect were introduced but before wave functions and duality. He felt that *Solids & Light* gave his students a concrete learning experience on energy levels within the context of everyday modern devices - LEDs.

When asked when they would incorporate *Solids & Light* in the physics curriculum, Teacher C indicated at the end of the year - after the electricity unit and at the beginning of year for those students who have chemistry backgrounds. He felt the materials would be appropriate for those students who had previously taken chemistry and had knowledge of probability electron clouds and orbitals. Teachers D and E indicated that they would implement the materials after introducing Ohm's law in the electricity unit. Teacher D, who taught a second year modern physics course, indicated that he would likely implement *Solids & Light* in a special topics course because it has a more flexible and less rigid schedule than a first year physics course.

All five teachers felt that they did not have enough time to prepare and would have liked access to the materials as soon as possible (preferably in the summer) so that they can have adequate time to prepare for teaching *Solids & Light* during the academic year. Teachers C and D admitted that they did not spend enough time preparing for teaching the unit and were just a few hours ahead of the students. Of all the teachers, Teacher A was the only one that enjoyed learning about the concepts introduced in *Solids & Light* at the same time his students did. Teacher D indicated that he would have liked to be introduced to the materials in workshop type environment so that he would be able to have the time try the investigation for himself to make sure they "work" and to identify the problems and difficulties associated with using the materials. Arons (1990) suggests that teachers must be guided slowly and carefully through the same experiences they wish to convey in their own classroom.

4.5 Conceptual Understanding of Solids & Light

Of the three instructors observed, only Teacher A (who taught modern physics at the boarding school) and Teacher C (who taught the junior accelerated physics and algebra-based physics courses) administered to their students an exam that assessed their understanding of the concepts introduced in *Solids & Light* and reported their results. Although both teachers used the questions provided in the *Solids & Light Instructor's Manual* to construct their tests, Teacher A administered to his students two different versions of the test with slightly modified questions while Teacher C administered to both his classes one test consisting of questions taken directly from the instructor's manual. Table 4-23 shows the exam mean scores (out of 100) and standard deviations as well as the highest and lowest exam scores for the students in these courses. Table 4-23 shows that the modern physics students performed much better on their exams than the accelerated junior physics and algebra-based physics students did on their exams. The modern physics students, however, had taken a slightly different exam than Teacher C's students. As a result, a direct comparison of the modern physics student exam scores cannot be made with the accelerated junior physics and the algebra-based physics student exam scores.

Table 4-23: Student Exam Scores

Course	Means (SD)	Lowest Score	Highest Score
Modern Physics	86.1 (10.8) n = 18	53	100
Accelerated Physics	42.2[1] (13.9) n = 21	18	76
Algebra-based Physics	29. 6[1] (12.5) n = 31	8	64

Note: Maximum Score = 100

[1] Denotes significantly different at $p < .05$.

Table 4-23 shows that the accelerated junior physics and algebra-based physics students did not fare well on their exam with mean scores that were less than 50% correct. The results of a t-test for independent samples reveals that the accelerated junior physics students performed significantly higher on the exam (a mean of 42.2) than the algebra-based physics students (a mean of 29.6). In all fairness to the accelerated junior physics and algebra-based physics students, these students completed the exam on the last day of the field test which happened to be the day before Christmas break, and the students were not made aware of the exam until the day before the test. These students were still wrapping up the activities on the day before the test. In addition, their instructor, Teacher C, at no time during the field test provided any reviews or discussions on what they learned previously. Most of the students also felt that the test was very different from the type of test they were used to taking. They felt the test was more difficult because it forced them to think.

One of the exam questions asked the accelerated junior physics and algebra physics students to construct the resulting spectrum of light emitted by a single gas atom when given the energy level diagram of the gas as illustrated in Figure 4-1. Figure 4-2 illustrates the three possible spectral lines with their respective energies. The magnitudes of these energies are determined by the energy differences between the energy levels as illustrated in Figure 4-1.

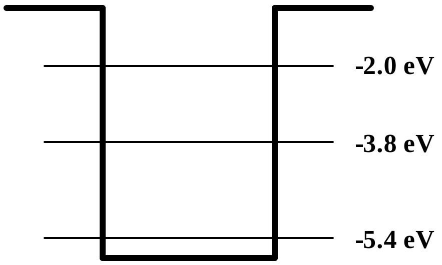


Figure 4-1: Energy Level Diagram of a Monatomic Gas

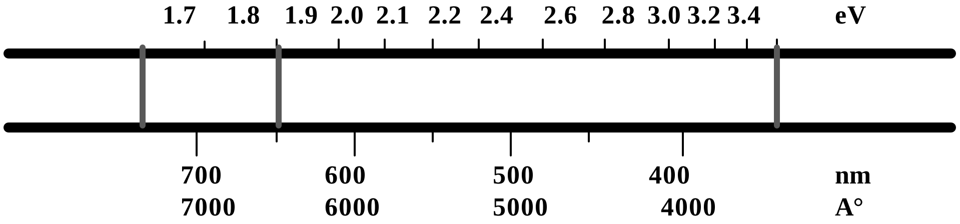


Figure 4-2: Resulting Spectrum of the Monoatomic Gas

Only one of the 21 accelerated junior physics students who took the exam failed to recognize that the resulting spectrum would be a spectral line pattern characteristic of a gas. However, only 8 of the 21 students (38%) were able to successfully identify at least 2 of the 3 spectral lines that resulted from Figure 4-1. Thirteen of the 21 students (62%) associated the energy values indicated on Figure 4-1 as the energies for the resulting spectral lines.

Only 2 of the 31 algebra-based physics students who took the exam failed to recognize that the resulting spectrum would be a spectral line pattern characteristic of a gas. However, only 5 of the 31 students (16%) were able to identify successfully at least 2 of the 3 spectral lines that result from Figure 4-1. Twenty-four of the 31 students (77%) associated the energy values indicated on Figure 4-1 as the energies for the resulting spectral lines. Recall that the computer program, *Gas Lamp Spectroscopy*, was developed to address the misconception that the energies of the resulting spectral lines of a gas are the same energies as the allowed energies for an electron bound to this gas atom. The results of this study seem to indicate that student interaction with the materials, computer programs, and written documents alone are not sufficient to develop an understanding of this concept. Student interactions with the teacher is also important with the teacher acting as a facilitator during discussions to ask qualitative questions that require students to focus attention on key issues, encourage reflection, and to have students elaborate on their ideas (McDermott, 1993). The warning that McDermott (1991) gives about not abandoning students to the isolation of individual computers must be extended to curriculum materials as well. The results of this study seem to indicate that the teachers involved in the study (with the exception of Teacher A) were not "secure" enough in really having an understanding of the subject matter to facilitate discussion. Arons (1990) warns that if teachers are not "secure" in the use of curriculum materials by really having an understanding of the subject matter than the materials will not be effective. The results seem to indicate that this was the case.

Another exam question asked students to identify the possible electronic transitions for an LED solid by using the energy bands and gaps illustrated in Figure 4-3. Students were also asked to describe the resulting spectrum of light emitted by this LED and to determine the voltage at which the light would suddenly become bright. The energy bands and gaps illustrated in Figure 4-3 result in an infinite number of electronic transitions with 6 of these having extreme values. These extreme values result from electrons having possible transitions that occur within each band from top to bottom (.7 eV and .3 eV respectively) to transitions that can occur from the top or bottom of the highest energy band (- 2.4 eV or - 3.1 eV respectively) to the top or bottom of the lowest energy band (- 4.5 eV or - 4.8 eV respectively). Because the transitions within the bands do not result in visible light, the resulting spectral pattern emitted by the LED is a broad, continuous spectrum that ranges from 1.4 eV (infrared) to 2.4 eV (green). The voltage at which the observed light would suddenly become bright would be about the size of the energy gap (in volts) which is 1.4 V.

Figure 4-3: Energy Bands and Gap of the LED Solid

Ten of the 21 accelerated junior physics students (48%) were able to identify at least 4 of the 6 possible extreme transition values. Only 6 of the 21 students (29%) were able to describe the resulting spectrum as a broad spectral band. However, none of the students were able to determine correctly determine the energy range of this spectrum and the voltage when the light suddenly becomes bright.

Eleven of the 31 algebra-based physics students (35%) were able to identify at least 4 of the 6 possible extreme transition values. Only three of the 31 students (10%) were able to describe the resulting spectrum as a broad spectral band. None of the students were able to determine correctly the energy range of this spectrum or the voltage at which the light suddenly becomes bright.

Teacher A asked one of his two modern physics classes the same question on the exam. From the representative sample that was reported, 3 of the 5 modern physics students (60%) were able to identify at least 4 of the 6 possible extreme transition values. All five students were able to describe the resulting spectrum as a broad spectral band. Three of the five students (60%) were able to correctly determine the energy range of this spectrum and the voltage at which the emitted light suddenly becomes bright.

Based on the results of the examinations, the modern physics students had higher levels of conceptual understanding of the quantum concepts introduced in *Solids & Light* than the accelerated junior and algebra-based physics students. However, the results are not conclusive on whether the important factor is the course, students academic background, teacher, or how the teacher implemented the unit. If anything, the results are positive in that they stress the importance of the teacher’s role as a facilitator of classroom discussion in an activity-based environment in which developing and reinforcing student conceptual understanding is a concern.

CHAPTER 5
CONCLUSION

This study investigated the applicability of *Solids & Light* in various secondary physics classrooms by examining the effectiveness of the unit and the associated instructional techniques in helping students make observations and developing conceptual understanding of the quantum principles introduced within the context of learning about LEDs. The study examined how teachers implemented *Solids & Light* in their classrooms and the resulting student/teacher interactions with these materials by using a non-participant observation protocol. Student and teacher difficulties and misconceptions were investigated. Students' and teachers' attitudes toward *Solids & Light* were also analyzed as well as how these attitudes and student and teacher interactions with the materials were affected by attitudes toward physics and computers, availability of resources, teaching experience and style, gender, and level of physics taught.

5.1 Implementation and Observed Student/Teacher Interactions

The first research question focused on how *Solids & Light* was implemented in each physics classroom, identifying difficulties associated with these implementations, and how the resulting student and teacher interactions with the materials and one another were consistent with the learning cycle. Based on formal and informal observations and informal interviews, the study found:

1) Teacher A, who taught a computer-based, second year, modern physics course at a private boarding school, modified *Solids & Light*s to accommodate the materials to his course, his students, and his teaching style. He utilized a circuit apparatus connected to a computer-based laboratory tool to collect data, presented potential energy diagrams in more detail, focused on class discussions with student-teacher questions and answers, gave fewer instructions to his students than the other teachers, and generally presented the application activities (i.e. Activity 5) as homework or short in-class demonstrations (i.e. Activity 7).

2) Teacher B, who taught a conceptual-based physics course at a public high school, utilized *Solids & Light* as developed with minor revisions and focused mainly on the concrete, observational aspects of *Solids & Light* that were found in the hands-on explorations and applications. Teacher B provided more instructions to his students and spent more time on Activity 1 than Teacher A as a result of having his students connect the circuit apparatus themselves. Teacher B, like Teacher A, provided his students with opportunities to review what they learned or observed previously.

3) Teacher C, who taught accelerated junior physics and algebra-based physics courses at the same high school as Teacher B, also utilized *Solids & Light* as developed with minor revisions and focused on the concrete, observational aspects of *Solids & Light*. Teacher C, like Teacher B, guided his students in connecting their own circuit apparatus for Activity 1 and

had his students spend more time on the activity than Teacher A. Teacher C's interaction with his students primarily focused on providing directions and instructions so that his students would be able to complete the activities on their own. Those activities that were conducive to class discussions (concept introductions) were assigned as homework. Teacher C, unlike Teachers A and B, limited the amount of discussion and review in order so that students could complete as many of the activities as possible.

4) Teacher D, who taught a computer-based, modern physics course, and Teacher E, who taught a honor seniors physics course, provided very little teacher interaction at the beginning of the field test. The resulting difficulties that arose as students did the activities caused the teachers to alter their instructional approach and to provide more instruction and guidance.

The level of or type of physics course or the students physics background affected the implementation of *Solids & Light* by determining the degree of quantum principles being introduced. For example, the second year, modern physics students taught by Teacher A were introduced to the full range of quantum principles found in *Solids & Light* from energy levels of electrons bound to an atom of a gas to potential energy diagrams to the p-n junction that makes up the LED. Although the algebra-based and accelerated junior physics students were introduced to most of these quantum principles, their exposure to these concepts were very brief as a result of Teacher C rushing them through the activities. The introductory, conceptual physics students, on the other extreme, were introduced only to the concepts of energy levels and bands as a result of only having completed Newton's laws and their teacher feeling that the abstract nature of the concepts associated with how an LED operates were not appropriate for his students.

The level of physics course and the teacher's teaching style determined the amount of instruction that was provided by the teachers during the implementation of *Solids & Light*. Although all the observed teachers provided their students with significant student interaction with the materials and the computer programs (with the exception of one conceptual physics class) which is consistent with the learning cycle, the observed classroom behaviors and the student/teacher ratios for the first 20 minutes of each class illustrate that the modern physics teachers (Teachers A and D) and the honors physics teacher (Teacher E) provided their students with experiences that were more consistent with the learning cycle (i.e. fewer instructions, less lecture, and discussions) than the introductory physics teachers (Teachers B and C). Teachers D and E, however, ran into trouble at the beginning of their field test when they found out that their students required more instruction and guidance than they originally thought was necessary.

The large degree of instruction and guidance provided by Teachers B and C to their students was very consistent with their teaching style which for Teacher B included guided learning and for Teacher C included lecture. Unfortunately, the degree of instruction and guidance provided to their students during the first 20 minutes was not consistent with the student exploration aspects of the learning cycle. A teacher spending 20 minutes or more on providing instructions on how to do an exploration or an investigation seems to defeat the objective of an exploration which is to give students a concrete, experience with the phenomena and concepts being introduced.

The level of physics course, the teachers teaching style, and the availability of resources determined how computers were being used during the *Solids & Light* implementation in the various classrooms. The modern physics students taught by Teacher A collected and graphed their current-voltage data by using a computer-based laboratory tool as a result of having access to the equipment and the course's (and teacher's) emphasis on using the computer. The physics students from the other courses collected and graphed their current-voltage data by using pencil and paper as a result of not having access to computer-based tools and/or the less emphasis on using the computer in their class.

In regards to the availability of resources, Teachers B, C, and D were most affected by the lack of resources which is reported in high school science classrooms (Neuschatz & Alpert, 1994; Weiss, 1994; Baird et al.,1994) and that existed in their classrooms when they implemented *Solids & Light*. These teachers had to be provided multimeters, breadboards, and spectroscopes. Teachers B and C had to share this equipment, a classroom to conduct spectral explorations, and a computer laboratory. The sharing of resources by Teachers B and C influenced the number of students in a group that were interacting with the materials and the computer programs. The lack of access to the computer laboratory changed a highly student interactive computer program into a demonstration computer program illustrated by Teacher B in a conceptual physics class. The lack of resources in Teacher D's classroom affected his implementation by students being forced to work with equipment that included mismatch combinations of alligator clip wires, breadboards, analog meters, and digital multimeters. On the other extreme, Teacher A had the resources available for his small classes so that two students would be able to work as a group and interact with the materials and computer programs as well as collect current-voltage data with computer-based laboratory tools.

The resources like the breadboards, multimeters, and spectroscopes are a necessary component of the activities for students to carry out their investigations. A careful balance, however, of need versus availability must be achieved so that the likelihood of the teacher having access to the equipment is increased which enhances the likelihood of a teacher implementing *Solids & Light* in his or her classroom. Although the amount of equipment needed for students to carry out the investigations can to some degree be minimized, the requirement of computers cannot because of the integration of the interactive programs with the written materials in *Solids & Light*. As a result, the situation that occurred with Teacher B who was forced to demonstrate the computer programs to one of his conceptual physics classes rather than having students directly interact with the programs as a result of a scheduling conflict for the computer laboratory, is unfortunately a possible scenario that could occur. The worst case scenario would be a situation in which a teacher has no access to any computers.

In regards to difficulties associated with the implementation of *Solids & Light* in the various physics classrooms, students from all the classes had some problems in connecting the circuits and in using the spectrometer to observe the spectra of various light sources. These difficulties were compounded by the facts that these experiences were firsts for many of these students and that the students, who desired assistance from the teacher when things didn't work, vastly outnumbered the one classroom teacher who would go from one group of students to the next offering assistance. This scenario was especially a problem in the large classes taught by Teachers B and C.

Teachers B and C also had to contend with occurrences of non-functional instructional student behavior that were not present in the advanced physics classes. This type of behavior is especially a problem in an activity-based environment in which students are involved in explorations of phenomena and the instructor is focusing on one group of students at a time. The occurrence of this chaotic behavior is determined by the degree of clarity and conciseness provided to the student to complete the given task by the instructional materials and the instructor. Teacher comments and behaviors can also determine the degree of these student behaviors. For example, Teachers B and C often referred to the exploration aspect of the activities as “playing”. This statement could send a message to the students that the exploration is not an activity to be taken seriously and can result in students exhibiting non-functional instructional behavior.

The worksheet nature of the student activities may have contributed to the misconceptions that some of the teachers had that the *Solids & Light* materials were self-standing and that all they would have to do is have the students do the activities on their own. In addition, all five teachers observed that their students were skimming over the written materials and going right to the investigations. The written student activities seem to have to much information for the students to digest at one setting. This may especially the case when Teacher B and C handed out the activities to their students on the same day the activity was to be completed. Teacher B attributed the problem of his students not reading the written activities with how he uses worksheets to assess his students’ conceptual understanding.

The difficulties encountered by the teachers and students could be attributed to the teachers not having enough time to prepare for teaching the materials. All the teachers admitted that they were learning about the materials at the same time as their students. Teachers C and D admitted that they were just a few hours ahead of their students. How a teacher implements the materials in his or her classroom is influenced by how “secure” the teacher is in understanding the subject matter, the pedagogical intent, and in using the materials (Arons, 1990). A teacher’s “security” in using the materials is not only a reflection of his or her understanding of the materials but also how much time was spent in preparing to teach the materials.

5.2 Student Attitudes Toward Solids & Light

The second research question focuses on identifying student attitudes toward *Solids & Light* and the associated instructional techniques and determining how these attitudes are affected by the level of physics course, computer usage, teacher’s teaching style and background, gender, and students’ attitudes toward physics and computers. In regards to the non-computer aspects of *Solids & Light*, the study found:

1) Teacher A’s modern physics students rated the effectiveness of potential energy diagrams significantly higher than the students of the other courses.

2) The modern physics students rated the effectiveness of the provided directions significantly higher than Teacher B’s conceptual physics students.

3) Teacher A's modern physics students, and Teacher C's accelerated junior physics and algebra-based physics students rated the effectiveness of the materials in developing understanding significantly higher than Teacher B's conceptual physics students.

4) Modern physics students were significantly more likely to recommend *Solids & Light* to their friends than the algebra-based physics students.

5) Students' attitudes toward physics were not significantly related to their willingness to recommend the activities to their friends.

6) Gender did not have any affect on students ratings of the non-computer aspects of the materials.

These results are quite positive. Students' prior attitudes toward physics did not determine if they would recommend the activities to their friends, and gender did not have any effect on student ratings of the non-computer aspects of the materials. Students, female or male, those who liked or disliked physics, were just as likely to recommend *Solids & Light* to their friends.

The modern physics students rating the effectiveness of the potential energy diagrams higher than the other students was not surprising considering that they were provided more instruction and discussion on the subject. The high effectiveness rating for the materials providing directions by the modern physics students can be associated with the fact that they were second year physics students who would require less direction and instruction than the other students.

The low ratings of the materials effectiveness in developing understanding by the conceptual physics students was very consistent with some of the comments made by these students that indicated that they didn't learn anything. Teacher C's students, however, reporting high ratings for *Solids & Light*'s ability to develop understanding is not consistent with the results of their exam. These inconsistencies between students' self-reported ratings of understanding and their achievement on the exam illustrate the limitations of relying on self-reported data to evaluate curriculum.

The modern physics students greater willingness to recommend *Solids & Light* than the accelerated junior physics students was not only a reflection of what the students thought about the materials but also a reflection of how the materials were used and presented. While Teacher A utilized teacher interaction that involved questioning and classroom discussion, Teacher C provided very little of these teacher interaction techniques. As a result, Teacher C's students low recommendation rating could be more associated with the students being rushed to complete as many of the activities as possible rather than the materials themselves.

In regards to students attitudes toward the computer aspects of *Solids & Light*, the study found:

1) Those students who interacted with the computer programs rated the effectiveness of *Gas Lamp Spectroscopy* and the general computer aspects of *Solids & Light* significantly higher than those students who did not interact with the computer programs.

2) Modern physics students and algebra-based physics students rated the effectiveness of *Gas Lamp Spectroscopy* significantly higher than the conceptual physics students who did interact with the computer programs.

3) Modern physics students rated the effectiveness of the *Energy Band Creator* computer program significantly higher than the conceptual physics students who did not interact with the computer programs.

4) Student effectiveness ratings of the *Semiconductor Device Simulator* computer program were not affected by the level of the physics course that the students were enrolled.

5) Modern physics students rated the computer aspects of the unit significantly higher than the conceptual physics students who did interact with the computer.

6) Students' effectiveness ratings of the computer aspects of *Solids & Light* were not significantly related to their attitudes towards computers.

7) Gender did not have any significant affect on student ratings of the *Solids & Light* computer programs.

8) Students did not give any particular computer program a significantly higher effectiveness rating than the other programs.

Again the results were quite positive. Neither students attitudes toward computers nor their gender influenced their attitudes toward any of the *Solids & Light* computer programs. Male or female students, those who were comfortable in using computers and those who were not, were just as likely to rate their interaction with the computer programs as a positive experience. Thus, the computer programs can be characterized as user-friendly which increases the likelihood that students and teachers will use the programs in their classrooms and be comfortable in using them (Escalada & Zollman, 1997; Escalada, Grabhorn, & Zollman, 1996).

Not surprising was that those students who personally interacted with the computer programs rated the effectiveness of the computer program higher than those who simply watched a demonstration of the program. The modern physics students in general rated the computer programs higher than the other students. These higher ratings of the computer programs by the modern physics students could be due to the degree of quantum principles introduced in their course and the degree of understanding of these concepts resulting in a greater appreciation of how the computer programs bridge what they learned in their explorations with the quantum principles being introduced. The following statements, “A good consummation of the work done in previous sections.” and “I wouldn’t have been able to understand LEDs without the use of *Gas Lamp Spectroscopy*.” made by modern physics students that reflect their attitudes towards *Solids & Light* reflect this belief.

The conceptual physics students (those who interacted with the computers and those who did not) in general gave the computer programs a lower rating than the other students. These lower ratings could be explained by the fact that the conceptual physics students out of all the other students had the least amount of experience in using computers in the physics classroom. This explanation, however, is inconsistent with the finding that the physics course did not have any effect on student comfort levels in using computers. The explanation, however, that the students ratings of the computer programs as well as other aspects of *Solids & Light* are affected by their understanding of the quantum principles being introduced is quite possible especially since the degree of quantum principles introduced in each physics course was different.

In general, the students indicated that they learned the most from what they considered to be the most fun, a result which is consistent with the results of other *Solids & Light* field tests (Escalada, Rebello, Gruner, & Zollman, 1997). The conceptual physics students especially seemed to focus on a set of concrete skills rather than on a set of concepts that they learned. The majority of the students from all the observed courses indicated that they liked the hands-on nature of the activities and the computer programs and considered the written activities to be the least fun aspect of *Solids & Light*.

5.3 Teacher Attitudes Toward Solids & Light

The third research question focuses on identifying teachers attitudes towards *Solids & Light* and determining how these attitudes are affected by the level of physics course and the teacher’s teaching style and background. The teachers indicated that their students learned how to view and interpret spectra, how to relate spectra to energy levels or bands, and about the different properties of LEDs, gas lamps, and incandescent lamps. Although potential energy diagrams are an essential part of *Solids & Light*, only

Teacher A made any mention of his students learning about potential energy diagrams. Teacher A, however, was the only instructor who had access to a draft of *Potential Energy Diagrams*.

The teachers indicated that they would recommend *Solids & Light* based on the hands-on investigations, visual and interactive computer programs, and the focus on conceptual understanding. Each of course, suggested some revisions in the materials. The teachers also mentioned that the strengths of the materials were that the students were responsible for their own learning and were motivated to carry out the investigations because they considered them to be like puzzles or challenges which they had to figure out (i.e. trying to connect three LEDs in such a way to get all of them to emit light or attempting to get a bi-color LED to light). The activities also gave their students ideas on what interdisciplinary science investigations could be done for future science fair projects and seemed to motivate those students who did not previously perform very well in the past. Thus, *Solids & Light* were very applicable in motivating students by increasing the relevance of physics to their everyday lives.

The teachers indicated that they would implement *Solids & Light* in an introductory physics course when electricity and magnetism is discussed (specifically right after Ohm’s law was introduced) at the end of the year or in a special topics course when the schedule is less rigid and more flexible. The field testers, with the exception of Teacher E who just finished introducing Ohm’s law, indicated that their students lacked the skills in setting up the circuit and using the multimeters to measure current and voltage. Teacher A, however, eliminated these prerequisites by making the circuit apparatus himself and by replacing the multimeters with a computer and computer interface. The problem of implementing *Solids & Light* so late in the year is that if a teacher runs out of time, the teacher is likely not to implement the unit to make room for what he or she is considered more important (Hobson, 1996). As a result, the number of prerequisites needed to complete the unit must be reduced in teachers to implement the unit earlier in the year.

The teachers indicated that the written materials including the student activities and instructor’s manual need to be revised. For example, the teachers felt the student activities provided too much background information as a result of their students not reading the worksheets and felt the questions were somewhat redundant and time consuming. The teachers felt that the instructor’s manual needed to provide more background information on the potential energy diagram and the concepts that explain how an LED works. The teachers also felt that the instructor's manual needs to be more comprehensive by providing a homework packet with solutions, a discussion guide, sample data, and background information that would enable teachers to answer questions frequently asked by students. The fact that one of the teacher's spent a few hours on the phone asking for instructional support indicates that the instructor's manual was not effective in providing the complete logistic support that Arons (1990) recommends.

5.4 Student Conceptual Understanding of Solids & Light

The last research question addresses the effectiveness of the computer programs, materials, and instructional techniques found in *Solids & Light* in helping students make observations and develop conceptual understanding of the quantum principles being introduced. In regards to the effectiveness of *Solids & Light* in helping students make observations, this aspect has already been addressed. In regards to the effectiveness of the unit in developing student conceptual understanding, the study found:

1) The modern physics students (taught by Teacher A) scored higher on the exam than the accelerated junior physics and algebra-based physics students (taught by Teacher C).

2) Although the accelerated junior physics students scored higher than the algebra-based physics students on the same exam, both classes were below the reasonable level of performance indicating very little conceptual understanding occurred.

3) Although the majority of the accelerated junior physics and algebra-based physics students were able to recognize the spectral pattern of a gas when given its energy level diagram, the majority of the students directly associated the energy levels with the energies of the resulting spectral lines.

4) When students were asked to identify the possible electronic transitions for an LED solid given its energy bands and gaps, less than 60% of the students were able to identify at least 4 of the 6 extreme transition values. Only the majority of the modern physics students were able to correctly describe the resulting spectrum as a broad spectral band and the voltage at which the emitted light suddenly becomes bright.

Since different exam questions were utilized, a valid direct comparison between the modern physics students' scores and the accelerated junior physics or algebra-based physics students' scores cannot be made. The modern physics students, however, did seem to score higher on the exam and have deeper understanding of some of the quantum principles introduced when compared to the other students. Although the *Gas Lamp Spectroscopy* computer program was created to address student misconceptions about the relationship between energy levels and spectral lines, the results of this study indicate that the written materials must be revised so that a more effective integration between the written materials and the computer programs must take place for these misconceptions to be eliminated.

The results, however, cannot and should not be interpreted to only mean that the written materials are solely responsible for these misconceptions and that only second year, modern physics students can perform relatively well on these types of questions. Other variables including the teacher and how the teacher implements the materials must also be considered. Teacher C's students were limited to being provided instructions and guidance on how to complete investigations rather than on classroom discussions and qualitative questioning that would provide students opportunities to focus attention on key points, encourage reflection, and to assess conceptual understanding (McDermott, 1993). The accelerated junior physics and algebra-based physics students spent most of the time frantically trying to complete as many of the activities as possible without really understanding the quantum principles behind them. Because quantum mechanics involves looking at the world from a perspective that few students have little experience in using (Niedderer et al., 1990), students need time to think about, comprehend, and internalize relationships between the concrete physical phenomena that they observe and the abstract, quantum principles being introduced. Thus, the results are positive in that they reinforce the importance of the teacher's role in developing understanding of the quantum principles being introduced in an activity-based environment by providing opportunities as well as the time to for students to develop concepts, think, reason, and perceive relationships (Arons, 1990). The curriculum materials and computer programs alone are not enough. The use of the computer and the materials themselves do not necessarily promote inquiry learning; the teacher and the students whose collaborative grasp of these tools constitutes inquiry.

The point that must be emphasized is that the modern physics students received instruction (especially during the first 20 minutes) that is mostly closely aligned with the *Visual Quantum Mechanics* philosophy. As a result, direct comparisons between the modern physics students' performance and the algebra-based physics and accelerated physics students' performance are particularly difficult. In addition, algebra-based and accelerated junior physics students indicated that the *Solids & Light* exam was their first exposure to a form of open-ended assessment that probed their conceptual understanding. As a result, taking an exam that was very much different from their experiences could explain some of the difficulties these students had on the exam.

5.5 Proposed Modifications to Solids & Light

To increase the applicability of *Solids & Light* in various high school physics courses and the likelihood that the unit would be implemented into these courses, modifications will be made to enhance the strengths and address the weaknesses of *Solids & Light* that have been identified in this study. A necessary modification to *Solids & Light* must involve a reduction of the number of .prerequisites required for the students to complete the activities. For example, the activities will be revised so that the need for the prerequisites of Ohm's law and electrical circuits will be eliminated (i.e. decrease emphasis on current-voltage measurements and connecting the circuit) which would allow a teacher to implement the materials in his or her physics curriculum after the topics of energy and energy conservation. References, however, to Ohm's law and electrical circuits will still be retained as an optional activity for those teachers who would like to implement *Solids & Light* upon completion of electricity. The objective of this change is to decrease time spent connecting circuits and increase time on learning a few quantum principles.

The activities and the apparatus used in these activities will be simplified (i.e. fewer questions, short activities that can be assigned as homework, collecting current data will be optional which would eliminate the need for two multimeters) so that less time and fewer resources are needed for students to do the investigations and less time is needed by the instructor to provide directions. An activity will be added to the unit that would provide a basic tutorial for those students (and teachers) who did not complete the *Potential Energy Diagrams* unit. The instructor's manual would include background information on the concept of potential energy diagram in addition to a discussion guide that would enable the teacher and students to develop a concrete understanding of the concept.

Revisions will also be made to the *Solids & Light* computer programs. For example, the *Semiconductor Device Simulator* computer program will be revised to remove such references to terms, such as fermi energy, which are not required for these activities. The elimination of any unnecessary terminology or visual features found in the computer software will reduce student and teacher difficulties and misconceptions that may occur when the programs are being used.

To provide "security" for a potential field tester of *Solids & Light*, the current instructor's manual would be revised to be more comprehensive by providing:

- a discussion guide to focus on key concepts and ideas,
- a solution key to eliminate ambiguity in the questions,
- sample data for the explorations for those students who have difficulty making observations,
- and qualitative homework questions to focus students' attention on key concepts and would allow them to reflect on what they had learned and apply this knowledge.

In addition, the manual, along with the student activities, will provide sufficient background information on the various concepts associated with how an LED operates (i.e. p and n type materials, acceptors, donors, fermi level) so that both the students and teacher would be comfortable in learning these concepts. A list of vocabulary terms used through out the unit and their meanings would also be readily available for the students and teacher in electronic and written form so that they would be able access the information any time they required the meaning of any of the terms.

5.6 Recommendations for Further Studies

Further studies on the evaluation of the other *VQM* instructional units should involve in some form the direct observation of the implementation of these instructional units in various physics classrooms. This study has identified some inconsistencies and problems that result when relying on only student and teacher questionnaires that utilize only self-reported feedback. Direct observation coupled with self-reported feedback allows the researcher to get a complete picture of how the materials were being implemented and the difficulties associated with the field test. In addition, the use of multiple data collection techniques allows the researcher to collect and analyze sufficient descriptive data which are important in determining applicability (Lincoln & Guba, 1985).

Because *Solids & Light* had the prerequisites of Ohm's law and electrical circuits, the teachers with the exception of Teacher E, had to introduce or reintroduce these concepts in addition to the quantum principles in order for students carry out the investigations as a result of not yet covering these topics in their courses. Introducing all these new concepts in a short period of time contributed to the difficulties encountered by the students as well as the teacher. Future studies should be done to determine the applicability of *Solids & Light* in various classrooms when the prerequisites have already been introduced. This was done to certain degree by collecting feedback from Teacher E's senior honors physics course.

Solids & Light was the first instructional unit that was developed for the *Visual Quantum Mechanics* project. *Luminescence: It's Cool Light!* introduces similar quantum principles as *Solids & Light* but within the context of luminescent devices (i.e. light sticks, fluorescent lamps, IR detector cards) and without the prerequisites of Ohm's law and electrical circuits. Thus, *Luminescence: It's Cool Light!* has the potential to be appropriate and applicable for a much broader audience than *Solids & Light*. In addition, *Luminescence* was developed based on the initial feedback collected from students and teachers who field tested *Solids & Light*. Thus, a number concerns identified by this study have to some degree been addressed in *Luminescence*. Future studies could be done to determine the applicability of *Luminescence* in various high school physics classrooms and to determine if indeed the concerns identified in this study have been addressed.

An important point of this study is that teachers may claim to like the pedagogical style of the learning cycle which is used in *Solids & Light* even though they may occasionally revert back to the teacher-centered approach when they do not feel comfortable with a certain aspects of the materials. As developers of the curriculum materials for the *VQM* project, we have assumed that the teachers who field test *Solids & Light* or any of the other *VQM* instructional units would be able to adapt activity-based, student-centered instructional materials that utilize interactive computer programs, and inexpensive devices like LEDs to introduce quantum principles in their physics classrooms. The implementation of *Solids & Light* in a physics classroom can be an overwhelming and frustrating task to handle for the students and teacher especially if the teacher:

- spends less than 10% of their class time introducing modern physics topics (Neuchatz & Alpert, 1994),
- has no formal background in quantum mechanics,
- feels unprepared to the recent developments and applications of physics to everyday life (Neuchatz & Alpert, 1994; Baird et al., 1994),
- has no experience in using interactive computer programs in an activity-based environment,
- has traditionally taught with the teacher-centered approach, and

- has no experience in using open-ended qualitative questions.

The difficulties encountered by teachers and their students may not be associated with the materials themselves but with a conflict that exists between the pedagogical intent of the materials and the teacher's teaching style. Future studies should involve field tests that include the participation of high school teachers who are familiar with and receptive to the learning cycle as an instructional approach so that difficulties attributed to the conflict in pedagogical intent and teaching style can be eliminated and comparisons can be made between field testers who utilize the learning cycle with those who use the traditional, teacher-centered approach. Future studies could involve field testers who have implemented the learning cycle in their physics classrooms by using the *PRISMS* materials (Unruh & Cooney, 1997; IPTF, 1993).

The results of this study indicate that a comprehensive teachers manual may not be enough to develop a teacher's "security" in the use of LEDs and interactive computer programs to introduce quantum principles in an activity-based environment. Future studies should investigate the effect of workshops to train teachers in these instructional techniques and to provide the necessary background in the quantum principles being introduced so that the evaluation of *Solids & Light* would involve field tests by teachers who start at the same point and utilize strategies that are conducive to student-centered approach. This approach is used by the *PRISMS* project (Unruh & Cooney, 1997; IPTF, 1993). Before any high school teacher can obtain the materials, the teacher must be trained in a one week workshop on how to implement *PRISMs* into their curriculum so that the conditions which were created when the project was evaluated are very similar. The same type of scenario would be appropriate for a potential *VQM* field tester especially since quantum mechanics is not a topic that is in most high school physics teachers backgrounds.

5.7 Conclusions

Based on the results of this study, the following instructional strategies of *Solids & Light* were the strengths of the unit which make the materials very applicable to all levels of secondary physics courses:

- hands-on activities that focus on concrete investigations of observable phenomena before abstract treatments, highly visual and interactive computer programs,
- the use of inexpensive materials, the focus on qualitative understanding, and

- interdisciplinary science topics.

These strategies, which motivated the students to make observations and to learn, are very consistent with current national science education initiatives and what secondary science teachers consider important in order for their students to learn (Weiss, 1994). These strategies have been used with students who do not have strong backgrounds in mathematics and science and who lack deep understanding of the relationships between concrete, everyday experiences, and the models of physics (Escalada, Grabhorn, & Zollman, 1996) and are very appropriate to use for all students to develop conceptual understanding.

Solids & Light appears to have all the key components to make its implementation a successful one. Both teachers and students see the potential of implementing the unit or at least aspects of the activities in their physics course. Since the teacher ultimately plays the key role in the success or failure of any new curriculum materials that are being implemented into the classroom (Arons, 1990) and based on the results of this study, *Solids & Light* must include a more effective integration into the existing curriculum and additional support necessary to make the instructor comfortable with the subject matter and pedagogical style if the unit is to be implemented widely in the physics classroom.

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APPENDIX 1.1

VQM Teaching Units Available for Fall, 1996 Classes

Solids & Light:

Available For Field Testing: Now   Refundable Deposit: $15
Prerequisites: Energy Conservation and definitions of current and voltage
Teacher supplied equipment: voltmeter, ammeter, spectroscope, and gas discharge tubes
Class Time: 9 hours

This unit begins by asking students to explore the electrical and spectral properties of the light emitting diode (LED). Students quickly learn that the combination of electrical and light emitting properties of the LED cannot be explained with any approach that uses classical physics. Following this exploration into the properties of LEDs, students are prepared to learn about discrete energy states in atoms, and within a short time, energy gaps and energy bands. A computer program both simulates the experiments that the students have done and visualizes the bands and gaps in a semiconducting material. It enables the students to make connections between the changes in energy states of electrons and the electrical and spectral properties of an LED. This unit concludes with practical and future applications of LEDs.

Waves and Wave Functions

Available for Field Testing: Now   Refundable Deposit: $15
Prerequisites: Energy conservation, *Solids & Light* recommended but not required
Teacher supplied equipment: laser, double slit, and strings
Class Time; 9 hours

Students begin with the observation that electrons can be diffracted. If a real electron diffraction apparatus is not available, they use a computer simulation. They then learn about wave functions and how the wave description of matter leads to an explanation of discrete energy levels in atoms. The wave behavior of matter is applied to real devices such as the electron microscope and imaginary ones such as the transporter on Star Trek.

Luminescence: It's Cool Light!

Available for Field Testing: Now   Refundable Deposit: $15
Prerequisites: Energy Conservation
Teacher supplied equipment: spectroscopes, black light, gas discharge tubes, thermometers, clip leads, and fluorescent lights
Class Time: 9 hours

Students explore and explain, using energy level and band diagrams, a variety of different types of light sources including glow-in-the-dark objects, fluorescent materials, and light sticks. They observe the light emitted by sources such fluorescence tubes and, with the assistance of a computer program, develop models for explaining how this light is emitted. The model is then applied to more complex devices such as the inexpensive detector which TV technicians use to determine if a remote control is emitting infrared light.

Potential Energy Diagrams

Available for Field Testing: August, 1997 Refundable Deposit: None
Prerequisites: Energy Conservation
Teacher supplied equipment: Air track or *PASCO* collision carts, magnets, MBL equipment
Class Time: 4 hours

Because graphs of potential energy versus distance are used extensively in quantum physics but seldom taught in classical physics, we created this unit to help students understand the value of potential energy diagrams in describing motion. The students explore a variety of situations involving changes of potential energy in a one dimension system which consists of a track and a series of magnets. By using computer-based data acquisition the students are able to see motion and its relation to energy-distance graphs. Thus they become prepared to use these types of diagrams in their study of quantum physics. (A version that does not require MBL is under development).

Quantum Tunneling: Exploring the Very Small

Available for Field Testing: Now Refundable Deposit: $10
Prerequisites: Energy Conservation, and the *Waves & Wave Functions*, *Solids & Light*, and *Potential Energy Diagram VQM* instructional units
Teacher supplied equipment: voltmeter and ammeter
Class time: 7 hours

Students begin by looking at images of surfaces and nanostructures. The question is posed about how such images could be obtained without disturbing the locations of atoms. A visualization program that describes the scanning tunneling microscope (STM) enables students to simultaneously view an STM image, a cross-section of the surface, and the potential energy and wave functions of these electrons. Students then observe electrical properties of a tunnel diode and look at a unique quantum effect in a relatively common electronic device. Using the wave nature of matter, students can understand the value of tunneling and see its application in several different physics phenomena. Thus, this unit brings together a variety of components from other units to help students understand how STM images are created.

For more information about these units or the Visual Quantum Mechanics project, contact:

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

Voice/Fax: (800)232-0133 ext. 7167 or (913)-532-7167
Direct Dial Voice: (913)-532-1612
email: kim@phys.ksu.edu
WWW: http:\\bluegiant.phys.ksu.edu

APPENDIX 3.1
Potential Field Tester Letter

Dear Potential *VQM* Field Tester:

During the past year, the *Visual Quantum Mechanics* project has been developing materials to teach quantum physics to high school and introductory college students. A brief description of the overall project is enclosed. We now have a few of our instructional units ready for field testing. A brief description of these units and their present status is also enclosed.

Prior to release for field testing, all materials are tested by students at Kansas State University. These students have not studied any concepts related to quantum physics, wave motion, or light prior to completing these activities. Thus, we feel that the prerequisites for using these materials are very minimal.

All of our materials emphasize hands-on activities and have interactive computer programs. The hands-on activities utilize equipment such as voltmeters, ammeters, spectroscopes, and gas lamps plus components which we provide. The computer programs will operate on any platform running Windows 3.1 or any Macintosh running System 7 or higher. More details about the equipment and the computer programs are enclosed.

We are very interested in having you test these materials with some of your students. Thus, I am making an offer which I hope you cannot refuse. Return the enclosed application to become a field tester with a check for $ 15 which will cover the cost of one copy of the written documents, computer disks with the programs, and materials for one set-up. Each additional set-up will cost $5. We will not process your payment immediately. Instead, we ask that you have some of your students complete the entire set of activities by December 31, 1996. ***If you send us copies of their evaluations of the materials as well as your own evaluation, there will be no charge for one complete set-up and two additional set-ups and you may keep the materials for future use in your classes***. The evaluation involves questionnaires which you and the students complete for each week of the activities. If we have not received the student activity sheets and your evaluation by January 15, 1996, we will process your payment at that time. If you choose to order more than two additional set-ups, we will have to charge you the $5 fee for each additional set-up over two, even if you return the complete evaluation materials by the deadline.

We will be continuing the development over the next two years. We hope that you will be interested in field testing these materials with your students and that we will hear from you soon. If you have any questions, please don't hesitate to contact us for assistance.

Sincerely,

Dean Zollman

Professor of Physics

APPENDIX 3.2

Information for Visual Quantum Mechanics Field Testers (Secondary School)
Application Form

Name____
__ (last) (first)

School____
__

Address____
___

City____ State__________ Zip

Code___________________

Phone________________________________ Fax __________________________________
(area code)(number) (area code) (number)

Home

Address____

City____ State__________ Zip

Code___________________

Home Phone_____________________________ e-mail_____________________________________
(area code)(number)

Physics in your School

List the approximate number of students who enroll in each physics course in a typical year.

	Total Number	**Male**	**Female**	**White**	**Afro-American**	**Hispanic**	**Native American**	**Other**
First Year Physics								
Advanced Placement Physics								
Other								

What percentage of class time is devoted to the topics listed below?

	Atomic Physics	**Nuclear Physics**	**Solid State**	**Elementary Particles**	**Quantum Mechanics**	**Other 20th Century Physics**
First-Year Physics						
Advanced Placement Physics						
Other						

How many teachers teach physics in your school? _____________

School Profile

Grade Levels 9 ☐ 10 ☐ 11 ☐ 12 ☐ Other ____________

Total number of students in the school: _____ Approximate percentage of males _____ females _____

Approximate percentage of

White ______ Afro-American ______ Hispanic ______ Native American ______ Other _______

Size of community in which school is located _______________

Approximate percentage of total student population which come from

inner city _______ suburban _______ large town _______ small town _______ rural _______

Approximate percentage of students eligible for free or reduced-price lunch ________

Teaching Experience

Academic Degree(s) and Year(s) Received:

Additional Academic Training:

Content Areas of Endorsement/Certification

How many years have you been teaching physics? ________

What else have you taught?

What else are you teaching now?

Computer Use

To what extent do you incorporate computers into your physics teaching? **(Please circle all that apply)**

1. Computers are not available to me at school…………………………………………………………..1
2. Computers are available but are not currently being used in my physics course……………………..2
3. Computers are available and are used:………………………………………………………………3
   - a) by me for instructional purposes in the classroom………………………………………a
   - b) by me for instructional purposes in the laboratory………………………………………b
   - c) by students in the classroom…………………………………………………………..c
   - d) by students in the laboratory…………………………………………………………..d
   - e) by me for grading or record-keeping…………………………………………………….e
   - f) Other uses (please specify) ____……….. f

What computer platform do you use?
Windows 3.1 ☐ Windows 95 ☐ Macintosh System 7 ☐

Order Information

Qty	Description	Deposit[+]	Subtotal
	Complete Set-Up[*]	$15.00	$
	Additional Set-Up[**]	5.00	$
	Thank you for your order!	**TOTAL $**	

Payment Method (circle choice) **Check Enclosed** **Purchase Order** **Visa** **MasterCard** **Discover**

P.O. # ______________________________

Cardholder's Signature: ____

Credit Card Number ☐☐☐☐☐☐☐☐☐☐☐☐☐☐

Exp. Date: ☐☐☐☐

[+] **Deposits will be returned when you submit the completed evaluation materials.**

[*] **Includes written documentation, computer programs, infrared detection card and one set-up**

[**] **Battery snap, resistor, potentiometer, trimmer tool, incandescent lamp and 7 LEDs**

APPENDIX 3.3

Request to Observe Classroom Letter and Consent Form (Instructor)

Dear *VQM* Field Tester,

Upon receiving your application to field test the instructional materials developed for the *VQM* project, we will process your order and send you these materials as soon as possible so that you can begin to review them at your convenience.

With the materials you will find a set of *Instructor* and *Student Questionnaires* that we ask you and your students to complete at the end of the first and second weeks of the unit. This information provides us valuable feedback on the effectiveness of our materials in motivating students, helping them to make observations, and developing student conceptual understanding.

While these questionnaires provide us valuable feedback on the materials we have developed, they are limited in providing feedback after the activities have been completed. An important and essential component to any evaluation process must include the ability to collect information directly from the students and instructor who are evaluating any type of new curriculum. As a result, we are making an offer to a select number of high school physics teachers who are interested in field testing *Solids & Light* in their classroom(s). We would like to observe the implementation of this unit in various high school environments. If you would allow us to observe your classroom(s) as you implement these materials and if you are selected, we would:

1) ***provide all the materials and computer programs needed for your students to complete the Solids & Light at no cost,***

2) ***be willing to loan out any equipment such as breadboards, multimeters, and spectroscopes, etc. (excluding computers) that would be necessary for your students to complete the unit,***

3) ***provide you the one complete set-up of materials and computer programs for each of the other VQM instructional units that we have developed, and***

4) ***provide you a modest stipend of $150.***

I would act as an external observer collecting information directly from you and your students through the use of a classroom observation protocol as your students complete the *Solids & Light* activities. I am conducting this study for the evaluation component of the *Visual Quantum Mechanics* project undertaken by our Physics Education Research Group at Kansas State University and for my own personal dissertation research. The results of this evaluation process will help us determine the effectiveness of our materials and what necessary modifications need to be made to increase the effectiveness of these materials.

If you grant permission for this observation to take place, I will observe your class on a daily basis during the two-week period that you plan on completing the unit in your classroom(s) and may ask you and your students to elaborate on your and their attitudes toward the materials. I will make every attempt not to disrupt the natural flow of the class. If you agree to this observation process, I will ask you to administer two short surveys to your students before my arrival. Each survey will take your students less than 5 minutes to complete. As an external observer, I cannot disrupt the natural flow the class during class. I can, however, provide any technical assistance and guidance in regards to the *Solids & Light* materials outside of the actual class time. As part of the evaluation process, we ask you and your students to complete short evaluation forms at the end of each week of the 2 week process to provide us feedback about our materials. In addition, we ask that you administer an exam that we have developed upon completion of the unit.

We are hoping to make these observations in various high school physics classrooms during the 1996 Fall and the early 1997 spring semesters. As such we request that if you are interested in this offer and if you live outside the state of Kansas, you give use us at least a 21-day notice of when you plan to implement *Solids & Light* in your classroom(s) so that we can make the appropriate travel arrangements.

This component of the study will last through the spring semester of 1997, but follow up studies may be conducted after that time. Records about this study will be kept indefinitely for my personal use. If you agree to an observation to occur in your classroom, I request your permission to quote you anonymously in reports and publications about this study. Your name and the names of your academic institution and students along with other identifying features will not be linked with the results of this study.

You will be provided a copy of this letter with your signature. Upon agreeing to the observation process, I will send you letters of informed consent to distribute to your students. Your students and their parents will need to sign these documents before my arrival to your school. Thank you in advance for your consideration.

Sincerely,

Lawrence T. Escalada

PS If you have any questions about this opportunity, please feel free to contact me at any time at:
email: escalada@phys.ksu.edu
Fax and voice mail: 1-800-32-0133 ext. 7167 or 913-532-7167
Direct dial voice: 913-532-1612

Instructor's Consent Form

I am interested in this opportunity and grant my permission for you to observe the implementation of *Solids & Light* in my physics classroom(s). My participation in the observation process is purely voluntary. I understand that my refusal to participate will involve no penalty or loss of benefits to which I would be entitled as a field tester for the *VQM* materials and that I may discontinue participation at any time without penalty or loss of benefits to which I am entitled.

If I have any questions about the rationale or method of this study, I understand that I may contact Larry Escalada via email (escalada@phys.ksu.edu), phone (913-532-1612), or voicemail or fax (1-800-232-0133x7167).

If I have questions about the rights of subjects in this study or about the manner in which the study is conducted, I may contact Brian Niehoff, Chair, Committee on Research Involving Human Subjects, 103 Fairchild Hall, Kansas State University, Manhattan, KS 66506, at (913) 532-6195.

Printed Name: ________________________________ **Date:** __________

Signature: ________________________________

Anticipated Dates of Field Test(s):[Note] ___________________________

Anticipated Equipment Needs excluding computers (i.e. multimeters, breadboards, and/or spectroscopes):

____

____

____

Anticipated types and number of physics classes that you plan on implementing *Solids & Light*:

____

____

____

[Note] **If you agree to the observation, I will maintain continuous contact with you up to the scheduled date of the field test so that we would both be aware of any schedule changes.**

APPENDIX 3.4

Request to Observe Classroom Letter and Consent Form (Science Chair and Administrator)

Dear Science Chair/Administrator,

This letter is to inform you that one of your physics instructors, Mr/Ms/Mrs, is implementing a set of instructional materials that has been developed for the *Visual Quantum Mechanics* project. During the past year, the Kansas State University Physics Education group has been developing materials for this project to teach quantum physics to high school and introductory college students. These materials help students discover some of the basic quantum concepts involved with modern technological devices such as light emitting diodes, fluorescent lamps, light sticks, glow-in-the-dark objects, and infrared detector cards.

The instructional techniques utilized in these materials include hands-on activities, inexpensive, everyday devices, and interactive computer programs which are consistent with the recommendations made by the *National Science Education Standards* and the *American Association of Physics Teachers*. These techniques allow the introduction of quantum principles to students much earlier than has been traditionally possible.

We are very excited about Mr/Ms/Mrs field testing our materials in his/her classroom and applaud his or her efforts to be open to new, innovative and modern approaches to teaching physics in an effort to make physics interesting to the students and to increase their technological and scientific literacy at the same time.

We are very excited about Mr/Ms/Mrs field testing our materials in his/her classroom and applaud his or her efforts to be open to new, innovative and modern approaches to teaching physics in an effort to make physics interesting to the students and to increase their technological and scientific literacy at the same time.

An evaluation process is an important component to the successful implementation of any new curriculum in the classroom. As a result, we are asking Mr/Ms/Mrs and his/her students to complete questionnaires that will provide us valuable feedback on the effectiveness of our materials in motivating students, helping them make observations, and developing their conceptual understanding.

While these questionnaires provide us valuable feedback on the materials we have developed, they are limited in providing feedback only after the instructional materials have been completed. An important and essential component to any evaluation process must include the ability to collect information directly from the students and instructor who are using the instructional materials. As a result, we would like to seek your approval to observe first-hand the incorporation of one of our instructional units, *Solids & Light* in Mr/Ms/Mrs physics class(es).

My role would be that of an external observer collecting information directly from the students and the instructor through the use of an observation protocol as the students complete *Solids & Light*. I am conducting this study for the evaluation component of the *VQM* project and for my own personal dissertation research. The results of this evaluation will help us determine the effectiveness of our materials and what necessary modifications need to be made to increase the effectiveness of these materials.

Mr/Ms/Mrs has already agreed for this observation to take place and I have sent him letters of consent for his/her students and their parents to sign. The purpose of this letter is to inform the students and their parents of the observation and to seek their consent to quote the students anonymously in reports and

publications about this study. The names of the academic institution, students, and instructors along with other identifying features will not be linked with the results of this study.
Science Chair/Administrator
Page 2

These observations are scheduled to take place during the scheduled class meeting time starting from ___ and ending upon the completion of the unit or ___. As an external observer, I will make every attempt not to disrupt the natural flow of the class. Prior to the observation, I will ask Mr/Ms/Mrs to administer to his/her students two short surveys. Each instrument will take the students less than 5 minutes to complete.

At the middle and end of the observation process, I will ask the students and Mr/Ms/Mrs to complete short evaluation forms to provide us feedback on the materials that we have developed. In addition, I may ask Mr/Ms/Mrs and/or his/her students to elaborate on their attitudes toward our materials. Upon completion of the field test, Mr/Ms/Mrs has the option of administering an exam consisting of questions that we have developed to the students.

We are excited about this opportunity and believe that your students as well as Mr/Ms/Mrs will benefit from this learning experience. We believe that Mr/Ms/Mrs should be commended and applauded for his/her efforts in attempting to make physics exciting and relevant for his/her students. Your school is very fortunate to have teachers such as Mr/Ms/Mrs.

I have enclosed an approval form for you to sign that grants us permission to conduct this observation. You will be provided a copy of this form with your signature. I look forward to the opportunity of being a visitor at your school during the indicated time.

Sincerely,

Lawrence T. Escalada

cc: Mr/Ms/Mrs

Science Chair's and Administrator's Consent Form

I have been informed of the observation process involved with the implementation of *Solids & Light* in Mr/Ms/Mrs physics classrooms and grant my approval for this observation to occur. I understand that any communication provided to the external observer about this study will be kept confidential. I understand that if the external observer uses any quotes taken from the students and/or instructor, these quotes will appear anonymously in reports and publications about this study. In addition, I understand the names of the academic institution, students and the instructor as well as other identifying features will not be linked with the results of this study.

If I have any questions about the rationale or method of this study, I understand that I may contact Larry Escalada via email (escalada@phys.ksu.edu), phone (913-532-1612), or voicemail or fax (1-800-232-0133x7167).

If I have questions about the rights of subjects in this study or about the manner in which the study is conducted, I may contact Brian Niehoff, Chair, Committee on Research Involving Human Subjects, 103 Fairchild Hall, Kansas State University, Manhattan, KS 66506, at (913) 532-6195.

Science Chair's/Adminstrator's Printed Name: ________________________________

Adminstrator's Official Title: ________________________________

Science Chair's/Adminstrator's Signature: ____________________________________
Date: __________

Please use the self-addressed envelope to mail this form to the address indicated on the front of the envelope.

APPENDIX 3.5

Request to Observe Classroom Letter and Consent Form (Students/Parents)

Dear Physics Students and Parents,

Mr/Ms/Mrs, your son's or daughter's physics instructor, has agreed to incorporate instructional materials in his/her classroom(s) that will introduce his/her students to some principles of quantum physics through modern devices, interactive computer programs, and hands-on activities. These materials have been developed for the *Visual Quantum Mechanics* project undertaken by our Physics Education Research Group at Kansas State University.

An evaluation process is an important component to the successful implementation of any new curriculum in the classroom. As a result, we will ask your son or daughter and Mr/Ms/Mrs to complete questionnaires that will provides us valuable feedback on the effectiveness of our materials in motivating students, helping them to make observations, and developing student conceptual understanding.

While these questionnaires provide us valuable feedback on the materials we have developed, they are limited in providing feedback after the instructional materials have been completed. An important and essential component to any evaluation process must include the ability to collect information directly from the students and instructor who are using the instructional materials. As a result, I am taking this opportunity to inform you of my intention to observe first-hand the incorporation of one of our instructional units *Solids & Light* that we have developed in the physics classroom. My role will be that of an external observer collecting information directly from the students and the instructor through the use of classroom observations as the students complete the activities. I am conducting this study for the evaluation component of the *VQM* project undertaken by our Physics Education Research Group at KSU and for my own personal dissertation research. The results of this evaluation process will help us determine the effectiveness of our materials and what necessary modifications need to be made to increase the effectiveness of these materials.

These observations will take place during the scheduled class meeting times starting _____ and ending upon the completion of the unit or _____. I will make every attempt not to disrupt the natural flow of the class. Prior to my observation, I will ask Mr/Ms/Mrs to administer to his/her students two short surveys. Each survey will take the students less than 5 minutes to complete.

As an external observer, I cannot disrupt the natural flow the class during class. I can, however, provide any technical assistance and guidance in regards to *Solids & Light* outside of the actual class time.

In the middle and end of the observation process, I will ask the students and Mr/Ms/Mrs to complete short evaluation forms to provide us feedback on *Solids & Light*. In addition, I may ask Mr/Ms/Mrs and/or his/her students to elaborate on their attitudes toward our materials. Upon the completion of these materials, the instructor has the option of administering an exam consisting of questions that we have developed to the students.

This component of the study will last through the spring semester of 1997, but follow up studies may be conducted after that time. Records about this study will be kept indefinitely for my personal use. I request your consent along with your son's or daughter's consent to quote him or her anonymously in reports and publications about this study. His or her name, the name of the instructor, or the name of the academic institution along with other identifying features will not be linked with the results of this study.

Please sign and date the enclosed permission form and have your son or daughter provide his or her signature. You will be provided a copy of this permission form with your and your son's or daughter's signature. I look forward to meeting your son or daughter during the observation process. All parties involved in this field test will benefit from this learning experience.

Sincerely,

Lawrence T. Escalada

Student's and Parent's Consent Form

I have been informed of the observation process that will occur in my son's or daughter's high school physics course as the students complete the instructional unit, *Solids & Light*. I understand that any communication provided to the external observer about this study will be kept confidential. I grant the external permission to quote my son or daughter anonymously in reports and publications about this study. I understand that his or her name and the names of the instructor and the academic institution as well as other identifying features will not be linked with the results of this study.

If I have any questions about the rationale or method of this study, I understand that I may contact Larry Escalada via email (escalada@phys.ksu.edu), phone (913-532-1612), or voicemail or fax (1-800-232-0133x7167).

If I have questions about the rights of subjects in this study or about the manner in which the study is conducted, I may contact Brian Niehoff, Chair, Committee on Research Involving Human Subjects, 103 Fairchild Hall, Kansas State University, Manhattan, KS 66506, at (913) 532-6195.

Student's Printed Name: ________________________________

Student's Signature: ________________________________ Date: __________

Parent's Printed Name: ___________________________________

Parent's Signature: _________________________________ Date: __________

APPENDIX 3.6

Letter of Appreciation

Dear Mr/Ms/Mrs and Physics Students,

I just wanted to take this opportunity to thank you and your students for field testing *Solids & Light* and for allowing an observer to monitor the implementation of the unit in your physics classroom at your school. We are very excited and enthusiastic about our approach to introducing quantum principles to high school and college students. The feedback that we have obtained from classrooms such as yours provide invaluable suggestions and recommendations on how we can increase the effectiveness of our materials in motivating students, helping them to make observations, and developing student conceptual understanding. Most importantly, by field testing the materials in an actual high school physics classroom, we can determine what about this approach "works" and what about this approach does not "work". Thus, you and your students have provided us a valuable service.

We believe that you should be commended and applauded for your efforts to introduce quantum principles to your students by using this new, innovative, and modern approach to teaching physics. You should also be commended for your efforts to make physics interesting to your students and to increase their technological and scientific literacy at the same time. Teachers such as yourself, who are willing to take risks in trying something new, make physics exciting and relevant to their students.

Your students, their parents, the Science Chair, and the Administrator should also be commended for allowing the observation to take place and for being open to innovative instructional strategies in teaching modern physics in the hope that learning physics would be made more relevant to the students' lives. Thank-you again for your participation and for allowing an outside observer be a part of the wonderful learning environment that exists at _____ High School.

Sincerely,

Lawrence T. Escalada

cc: Science Chair
Administrator

APPENDIX 3.7

A Scale to Measure Attitudes Toward Physics[ã] *Form A* *Edited by H. H. Remmers*

Name: ___________________________ **Today's Date: ___/ ___/ ___**

Gender (Circle One): Male Female **Grade (Circle One): 9 10 11 12**

School: ____________________________ **City: __________ State: __________**

Instructions: The following is a list of statements about physics. Place a plus sign (+)sign before each statement with which you agree. There are no right or wrong answers to these questions and your answers will not affect your grade.

_____ 1. No matter what happens, physics always comes first.

_____ 2. Physics has an irresistible attraction for me.

_____ 3. Physics is profitable to everybody who takes it.

_____ 4. Any student who takes physics is bound to be benefited.

_____ 5. Physics is a good subject.

_____ 6. All lessons and all methods used in physics are clear and definite.

_____ 7. I am willing to spend my time studying physics.

_____ 8. Physics is a good hobby to have.

_____ 9. I don't believe physics will do anybody any harm.

_____ 10. I haven't any definite like or dislike for physics.

_____ 11. Physics will benefit only the brighter students.

_____ 12. My parents never had physics, so I see no merit in it.

_____ 13. I am not interested in physics.

_____ 14. Physics reminds me of Shakespeare's play -- "Much Ado About Nothing."

_____ 15. I would not advise anyone to take physics.

_____ 16. Physics is a waste of a time.

_____ 17. I look forward to physics with horror.

APPENDIX 3.8

Scoring Table for the Scale to Measure Attitudes Toward Physics Form A

Scale Value	Item #	Scale Value	Item #
10.3	1	5.5	10
9.6	2	4.7	11
9.2	3	3.6	12
8.9	4	3.1	13
8.5	5	2.6	14
8.1	6	2.2	15
7.7	7	1.6	16
6.5	8	1. 0	17
6.1	9		

The median scale value of the statements marked with a plus sign is the attitude score. If an odd number of statements is thus checked with a plus sign, the scale value of the middle item of those checked gives the score. For example, if nine statements are checked of which the fifth one is item # 10, the score for the student is 5.5, the scale value of item # 10. If an even number of items is checked, the student's score is the scale value half-way between the two middle items. For example, if ten items are checked of which item # 6 and # 11 are the fifth and sixth in order, the student's score will be the scale value of item # 6 (8.1) plus the scale value of item # 11 (4.7) divided by 2 which is (8.1 + 4.7) / 2 = 6.4.

APPENDIX 3.9

Attitudes Toward Computer Technologies Instrument

Name: ____________________________ **Today's Date: ___/ ___/ ___**

Gender (Circle One): Male Female **Grade (Circle One): 9 10 11 12**

School: ____________________________ **City: __________ State: __________**

Instructions: Please circle the number that indicates how you feel about the following statements. Use the following scale to indicate your feelings. There are no right or wrong answers and your ratings will not affect your grade.

1 = strongly disagree (SD)
2 = disagree (D)
3 = agree (A)
4 = strongly agree (SA)

	SD	**D**	**A**	**SA**
1. I am confident in my ability to be successful in a course that requires me to use computers.	1	2	3	4
2. I feel at ease learning how to use computers.	1	2	3	4
3. I am not the type that does well in using computers.*	1	2	3	4
4. The thought of using a computer makes me feel tense and uncomfortable.*	1	2	3	4
5. I do not feel threatened or intimated by computers.	1	2	3	4
6. I get nervous around computer because I feel like I might break them.*	1	2	3	4
7. Computers are too complicated to be of much use to me.*	1	2	3	4
8. I feel comfortable about my ability to use computers.	1	2	3	4

In the space provided below, describe your experience in using computers including the type of computer platform (*Macintosh*, PC without *Windows*, or PC with *Windows*) and computer applications (software, network, etc.) you have experience in using.
____
____
____
____
____

***represents negatively-phrased items.**

In the space provided below, describe your experience in using computers including the type of computer platform (*Macintosh*, PC without *Windows*, or PC with *Windows*) and computer applications (software, network, etc.) you have experience in using.

____
____
____
____
____

***represents negatively-phrased items.**