THE EFFECTS OF PROFESSIONAL DEVELOPMENT ON INSTRUCTIONAL STRATEGIES AND THE RESULTING INFLUENCES ON STUDENT LEARNING FOR A PHYSICS CURRICULUM

by

LAURIE CLEAVINGER

B.S., St. Mary College, 1978

M.A., University of Kansas, 1984

AN ABSTRACT OF 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

2009

Abstract

In this study, the professional development for a physics program called *Visual Quantum Mechanics* (*VQM*) was observed and analyzed. Four of the participants in a summer institute as Kansas State University (KSU) volunteered to be observed by the researcher as they implemented the program into their classrooms during the next academic year. Observations were used to determine the effectiveness of the instructional strategies that they used. The students' perception of the laboratory sessions was evaluated and student understanding of the physics concepts also was determined.

Qualitative and quantitative data analyses indicated that the professional development as presented and supported by the KSU team provided teachers with the information necessary to use the *VQM* program successfully with their students. However, only 30% of the teachers implemented the program during the following school year. Instructional strategies advocated by the *VQM* program included use of the hands-on equipment and computer simulations as well as discussion techniques. Observations revealed that students were more attentive during laboratory activities and less attentive during the discussions. Nevertheless, discussion proved to be a valuable component of this process. The researcher concluded that high quality professional development encouraged teaches to implement *VQM* in their classrooms. Although teachers did not always follow the instructional strategies advocated by the program, the inquiry-based hands-on activities and computer simulations kept students attentive. As a result, there was significant learning directly attributable to *VQM* for the students who participated in the study. Students who finished a complete learning cycle within the activities showed more significant learning than students who did not complete a learning cycle.

Professional development can be designed to encourage teachers to implement new skills. For *Visual Quantum Mechanics*, emphasizing the importance of the whole class discussions, presenting the connections between the concepts and the science standards, and focusing on strategies for implementation will provide additional confidence to teachers as they implement the program in their classrooms.

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Table of Contents

List of Figures

List of Tables

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Dedication

I dedicate this project to my two granddaughters, Vivian Marie and Raegan LeeAnn who were both born in the midst of this process. May all your dreams come true.

CHAPTER 1 - Introduction

"Teacher success = student success."

(Stronge, 2007, p. 105)

Research shows that the single most important school-related factor in raising student achievement is the quality of the teacher in the classroom (Marzano, 2003 and NBPTS, 2007). A teacher has the ability to transfer knowledge so that students can understand and apply skills for themselves (Stronge, 2007). The result of effective teaching is higher student motivation and greater gains in learning (McCombs and Miller, 2007). Effective teachers need to be knowledgeable in their content area, in pedagogy (Stronge, 2007 and Tobin, Tippins and Gallard, 1994), and in pedagogical content knowledge (Shulman, 1987). In addition, effective teachers are highly reflective. They believe that they can make a difference with a diversity of learners (McCombs and Miller, 1997) because they feel they are responsible for the success of their students (Stronge, 2007). They see teaching and learning as a partnership with their students.

Effective teachers care about their students and believe that students should be responsible for their own learning so they provide opportunities for the student to make choices in their learning. Effective teachers are passionate about their content areas as well as experts in their fields (McCombs and Mille, 2007). Therefore, to ensure student success, there must be an effective teacher in every classroom. Teachers may become more effective through the use of a high quality curriculum and effective instructional strategies and participation in high quality professional development. This study explored the professional development provided by Kansas State University (KSU) to middle and high school physics teachers through a group called QuarkNet. The instructional strategies used by the teachers as they implemented a physics curriculum called *Visual Quantum Mechanics* were observed and the resulting student learning was determined. This study explored the relationship between professional development strategies, a physics curriculum, effective teaching and student perceptions and learning.

Effective teachers set high expectations for their students and are consistent in the manner that they are used in the classroom (Whitaker, 2004). Teachers know that the expectations for student learning are based on national and state level learning standards in the core content areas. The high expectations for student learning translate to high expectations for teachers as well (Whitaker, 2004). While the standards define the content of instruction, the curriculum defines the emphasis and perspectives on the content (Krueger and Sutton, 2001). It is the plan for learning that provides the content and purpose for an educational program (van den Akker, 1998). The curriculum should be based on the standards because the standards identify what the students should know and be able to do. In science, this means that students will have the information and understanding of concepts in science that drives the processes necessary for making personal decisions, participating in civic and cultural affairs and becoming economically productive (NSES, 1996). In other words, they will be scientifically literate (Krueger and Sutton, 2001). Students should have an understanding of the natural world (NSES, 1996). They should be able to apply scientific thinking in real-life problem solving (Krueger and Sutton, 2001 and NSES, 1996). They should be able to intelligently debate scientific issues and use science knowledge to be an economically productive citizen (NSES, 1996). This translates to science for all students, not just those who would choose a science related career (Bybee and Ben-Zvi, 1998).

The curriculum is only a guide. Local school districts determine the way science content is organized, emphasized and taught. Teachers are the interface between the standards and the students. As such, they must balance the students' prior knowledge and future needs as they plan for daily lessons with the diverse student population in mind (Krueger and Sutton, 2001). To be successful, a curriculum or program must be both coherent and articulate. Coherence connects the ideas and skills and allows them to build on one another over time. Articulation describes the relationships between the elements within the program so that they challenge the students to reach deeper understanding. To achieve coherence and articulation, a program should focus on important concepts and skills, develop understanding over several years in logical pathways, show connections between concepts and skills, and explicitly assess and diagnose students along the way (Krueger and Sutton, 2001). A curriculum should be designed to build upon the student's prior knowledge. It should include strategies, resources and materials that the teacher needs for implementation and assessment. The teacher's needs in areas such as classroom management and program effectiveness should be included in the curriculum as well as addressing the cultural and educational context in which it will be used (Bybee and Ben-Zvi, 1998).

No matter what the curriculum, teachers make the final decisions about which instructional strategies to use based on a wide variety of learning styles, backgrounds and interests (Bybee and Ben-Zvi, 1998, Krueger and Sutton, 2001). It's the people, not the programs that make schools successful (Whitaker, 2004). An effective teacher uses a multitude of instructional strategies chosen to meet the needs of the students (Danielson, 2007 and Stronge, 2007) Instructional strategies are the manner in which a teacher uses materials, media, setting and behaviors to create a learning environment that fosters learning. These strategies are placed on a continuum with teacher-centered classrooms on one end and student-centered classrooms on the other end. In a teacher-centered classroom, the student is more passive. Teacher strategies would include lecture, whole class discussions, demonstrations and questioning techniques. In a student-centered classroom, the student is more active. These strategies include lab, inquiry activities, small group discussions, computer simulations and field trips (Hofstein and Walberg, 1995). In a student-centered classroom there is a combination of foci. One focus is the individual learner's heredity, talent and interests. The other focus is on knowledge about learning and how it occurs. Strategies in these classrooms encourage high levels of motivation, learning and achievement (McCombs and Miller, 2007). Effective instructional strategies are an important component of effective teaching.

The choice of quality materials (Krueger and Sutton, 2001) and instructional strategies used with a new program in the classroom will be influenced by professional development. Professional development for a curriculum should include the content and pedagogy that the teacher needs to know. It should also explain the philosophy, materials, expected outcomes and assessment strategies (Bybee and Ben-Zvi, 1998). This requires sufficient time and resources (Krueger and Sutton, 2001). The Professional Development Standards from the National Science Education Standards (NSES), shown in Figure 2.5, describe the characteristics of high quality professional development in detail.

Professional Development Standard A links professional development to science content and inquiry methods of learning by stating that science teachers need a strong base in science content obtained through the methods of inquiry (NESE, 1996). High quality professional development addresses content and pedagogy (Danielson, 2007, Garet, et al., 1999, NSES, 1996, and van den Akker, 1998) through learning opportunities that build on prior knowledge, immerse the teacher in stimulating processes, allows for teamwork (which encourages collegial relationships), and extend over a sustained period of time (Garet, et al., 1999 and NSES, 1996). This provides teachers with the opportunity to stay updated on their content areas, improve their teaching practices, and increase the use of technology (Danielson, 2007). Professional development should model the methods that ought to be used with the students and how those methods can be adapted for different types of students (Garet, et al, 1999). This is directly related to Professional Development Standard B from NSES which describes professional development that integrates knowledge of science content, learning, pedagogy, and students as it addresses teachers' learning needs (NSES, 1996). Professional Development Standard C in NSES promotes lifelong learning which includes the skills of reflection, collaboration, and research to improve teaching skills. For all of this to happen, professional development must be planned with specific goals in mind that meet the needs of the teacher, provided collaboration, and recognize the culture of the school and community, and an assessment program that provides feedback. This is stated in Professional Development Standard D of the NSES (NSES, 1996).

High quality professional development also will provide teachers the time needed to assimilate the information, try to apply the information with students, and re-gather for reflections and feedback (Garet, et al, 1999). As Standard C describes, professional development should build understanding and the ability to become a life-long learner which can require the help of peers, coaches and mentors. Life-long learning not only requires time for reflection but also for access to research and the opportunity to develop experiential knowledge (NESE, 1996). Professional development only makes sense if it is coherent and integrated (Standard D). It should extend over a period of time, be continuously reinforced, and include time for practice. Collaboration between teachers, administrators, professional organizations and parents is an important component of this as well (NSES, 1996).

Effective teachers are life-long learners who model this process for their students (Danielson, 2007). They understand that the process of teaching provides an arrangement of the environment which allows students to interact and learn (Joyce and Weil, 1996). How students learn, what they learn, and how much they learn is directly related to the effectiveness of the teacher (Stronge, 2007). Becoming an effective teacher is a life-long journey that requires collegial relationships, observation of other teachers, appropriate peer feedback and learning experiences that can be provided by professional development (Stronge, 2007). Consequently, high quality professional development should lead to the use of higher quality curricula and instructional strategies that should, in turn, influence student learning.

Background and Rationale

Visual Quantum Mechanics (VQM) is a physics curriculum based on modern physics concepts. It was written in 1995 by the Kansas State Physics Education Research Group as an activity-centered instructional approach based on the use of the learning cycle (Escalada, 1997). Students explore the electrical and spectral properties of LED's and incandescent lights as they relate to quantum principles. The program includes hands-on activities, computer simulations, and applications problems within five units.

QuarkNet is a project funded by the National Science Foundation (NSF), the United States Department of Energy (DOE), ATLAS, CMS and Fermilab. The goal of the project is to help teachers reach a deeper understanding of physics content with an emphasis on inquiry learning and modern (particle) physics concepts. There are approximately 50 universities and labs, including the physics department at KSU, participating in the QuarkNet program. Since the *Visual Quantum Mechanics* program was designed to build conceptual understanding of modern physics with an emphasis on inquiry learning, the QuarkNet group at KSU is encouraging physics teachers in Kansas to use this curriculum in their classes. A series of professional development opportunities was designed and conducted to enhance the implementation of the *Solids & Light* unit.

The KSU QuarkNet group focused its recruitment of participants on rural schools in Kansas. Teachers came to participate in the QuarkNet Project from across the state of Kansas with a wide variety of teaching experiences. To encourage additional involvement, a search for new teachers was conducted during the spring of 2007. The new teachers attended a one-week long professional development that included information about the *Visual Quantum Mechanics* program. The professional development lasted multiple days, allowed time for reflection and collaborations and promised continued support for those teachers who used the program in their classrooms. It was hoped that the instructional strategies used by the teachers as they implemented *Solids & Light* in their classrooms would influence student learning of modern physics concepts. To more fully assess the success of the professional development provided by the QuarkNet program at KSU, it was important to explore the implementation of the *Solids & Light* unit and its impact on teaching and learning as well as the effectiveness of the professional development designed to enhance the implementation of the *Solids & Light* unit.

Statement of the Problem

Lawrence Escalada previously evaluated the *Quantum Visual Mechanics* program in 1996. He investigated how implementation of the *Solids & Light* unit was influenced by the student and teacher interactions with the materials, student and teacher difficulties and misconceptions, and student and teacher attitudes. He also evaluated how student and teacher interactions were affected by the their attitudes toward the materials, physics, and computers, the availability of resources, the teacher's gender and teaching experience and the level of the physics class (Escalada, 1997).

The purpose of this study was to investigate the implementation of the *Solids & Light* unit from *Visual Quantum Mechanics* and the professional development strategies conducted to enhance the implementation of this unit. More specifically, this investigation has been designed as a naturalistic inquiry case study to explore how implementation of the physics unit was affected by the professional development that the teachers received to prepare them to implement the unit. The case study also was designed to investigate students' conceptual understanding of the physics concepts presented through the unit and students' perception of the laboratory environment and how these perceptions affect students' interaction with the materials in the program.

Research Questions

How does the professional development for *Visual Quantum Mechanics* influence teachers' implementation of the program?

a. How does the professional development affect the classroom implementation of individual activities within the program?

b. What instructional strategies are most commonly used by the teachers using the *Solids & Light* unit?

How does implementation of *Solids & Light* affect student learning?

a. How does student perception of laboratory experiences affect their interaction with *Solids & Light* materials?
b. Do students develop a conceptual understanding of the quantum mechanics in the unit?

Summary of Research Design

This study was a naturalistic inquiry case study of the use of a physics program called *Solids & Light* in several high schools in Kansas. The potential population was the teachers who attended the week-long QuarkNet institute at Kansas State University during July 2007. These teachers were invited to volunteer to participate in the study. Data were collected to determine how the professional development influenced the use of *Solids & Light* in the physics classroom and how the instructional strategies and materials affected student learning. The data sources were both qualitative and quantitative. The researcher used a Classroom Observation Protocol to examine the teaching strategies and student use of materials. Qualitative data included surveys, questionnaires and interviews. Some of the questions were designed as Likert scales. Quantitative data included a frequency chart within the Classroom Observation Protocol, the Science Laboratory Environment Inventory, and a pre/post test for student learning. This research design will be explained more fully in chapter three.

Assumptions of the Study

Within this study, methodological assumptions were made. First, it was assumed that the naturalistic inquiry approach would answer the research questions. The qualitative data provided a detailed view of how the professional development influenced the use of the *Solids &*

Light program. The data show the teaching strategies used by the teachers as they implemented the curriculum unit. The quantitative data has complemented this view of the observed classrooms. It also was assumed that the qualitative data would be somewhat subjective in nature. Because qualitative data has an emergent nature, it was assumed that there may be unexpected outcomes. These were used to further identify patterns that may occur throughout the study. It was assumed that the teachers and students who volunteered to participate were truthful in their answers to the questionnaires, interviews and surveys.

There were assumptions directly related to *Solids & Light*. It was assumed that the teachers who volunteered to participate attended the professional development institute for the necessary background on the program. It was assumed that the students are enrolled in a high school level physics class and had the appropriate prerequisites that would allow them to be successful in learning the content.

Limitations and Boundaries of the Study

Boundary conditions include the following statements.

- Data collection was limited to the professional development and implementation of the *Solids & Light* unit and their impact on teaching and learning.
- The population in the study was limited to those teachers who participated in the 2007 QuarkNet summer institute.
- Research results, interpretations and conclusions are limited to the teachers and students involved in the study. The researcher does not intend to generalize the results beyond these teachers and students. However, readers may determine the transferability of these findings to their own environment.
- This study is not an evaluation that compares *Solids & Light* to another curriculum as there are limited curricular resources for this content making comparisons challenging.

Possible limitations that must be addressed during the course of the study include the following.

- The researcher's role as a QuarkNet member may influence her interpretations of the data.

- The researcher's use of the *Solids & Light* program prior to the 2007 summer institute may influence her interpretations of the data.

To reduce the above limitations, the researcher was open-minded as the data were collected, followed proper research protocol, and tended to other quality considerations that might impact the credibility of the study as described in chapter three.

Significance of the Study

The results of this study are intended to be beneficial for the researcher (who uses the program with high school physics students) and for other teachers in the area of science, specifically physics classrooms, that are similar to those in the study. Although this study will not be used to change the *Solids & Light* program as the evaluation in 1996 did, it may influence the presentation of the program in later professional development sessions. Individuals interested in the design of high quality science curricula, professional development, and implementation support may also draw insights from this study as it relates to their particular contexts.

Summary

This study sought to determine how professional development influences the implementation of the *Solids & Light* unit and how the instructional strategies and materials used as part of this curriculum affected student learning. Chapter Two will review the literature related to how students learn, how teachers teach, how teaching strategies must connect teaching and learning and the professional development that improves teaching skills. Chapter Three will explain the methodology and design of the study, to include the factors that determined the choice of teachers in the study, the types of data collected and how these data were analyzed. Chapter four will present the data resulting from the study of the *Solids & Light* unit. Chapter five will discuss the interpretations, conclusions and recommendations that become apparent from the data.

CHAPTER 2 - Review of Related Literature

The Effective Teacher

"Better Teaching = Better Learning = Better Schools". (NBPTS, 2007)

Research shows that the single most importance school-related factor in raising student achievement is the quality of the teacher in the classroom (Marzano, 2003, NBPTS, 2007, and Whitaker, 2004). Teaching is a complex process requiring multiple skills. Teachers must have higher-order teaching skills if students need to learn higher-order thinking skills (NBPTS, 2007). The complexity of teaching extends over several areas of the job. Teaching is demanding physically, emotionally, and cognitively. It combines the skills of business management, human relations and theater arts and it is highly stressful (Danielson, 2007). As a result of this complexity, the National Board for Professional Teaching Standards was founded in 1987. Its mission is to increase the quality of teaching and learning using national standards for experienced teachers. As teachers work toward Nation Board Certification, they produce a portfolio that represents their classroom activities and their ability to uphold the National Teaching Standards (NBPTS, 2002). There are currently 55,000 Board Certified Teachers (NBPTS, 2007). The National Board Standards consist of five core propositions as shown in Figure 2.1.

Figure 2.1 The Five Core Propositions – NBPTS, 2002

1. Teachers are committed to students and their learning.
2. Teachers know the subjects they teach and how to teach those subjects to students.
3. Teachers are responsible for managing and monitoring student learning.
4. Teachers think systematically about their practice and learn from experience.
5. Teachers are members of learning communities.

Teachers are not able to do their job unless they truly believe that all students can learn. However, they must also acknowledge that students are individuals who learn in their unique ways and paces. In order to make the necessary adjustments for student needs, teachers must understand student development and the process of learning plus consider the influence of context and culture on the learning process (NBPTS, 2002 and NCTAF, 1996). Teachers should know the students both formally (such as in the classroom) and informally by demonstrating interest in students outside of the classroom (such as personal situation, or being present at athletic activities). This increases student self-esteem and motivation (Stronge, 2007).

The most important factor in student learning is the effectiveness of the teacher (Marzano, 2003 and NBPTS, 2007). Effective teachers view the processes of teaching and learning as a partnership between teacher and students. These teachers understand learning theory and use instructional strategies that are most effective (McCombs and Miller, 2007). Instructional strategies describe the methods used by teachers for materials, media, setting and behaviors that produce an environment that fosters learning. Strategies can be found on a continuum that starts at one end with teacher centered activities which include lecture, demonstration and questioning techniques that allow the student to be more passive. The continuum extends to the other end with student centered activities which include labs, inquiry activities and computer simulations (Hofstein and Walberg, 1995). To use the instructional strategies effectively, teachers need to understand pedagogy, be knowledgeable in their content area (Stronge, 2007 and Tobin, Tippins and Gallard, 1994) and be able to teach the content using the instructional strategies that are appropriate for the students (Shulman, 1987). Becoming an effective teacher is a life-long process of learning which requires high quality professional development (Danielson, 2007, Garet, et al., 1999, NSES, 1996, and van den Akker, 1998). Three characteristics of an effective teacher are an understanding of learning theory, the use of instructional strategies that match the students' learning and the maintenance and growth of teaching skills obtained through attendance at professional development opportunities.

Learning Theory

In order to use the appropriate classroom organization and management, instructional models and strategies, and classroom discourse, teachers must have an understanding of how students learn – in other words – how to apply learning theory to classroom practice.

Cognitive Development (Piaget's theory)

According to Piaget, an individual learns as one progresses through several stages of cognitive development: the sensorimotor stage, the preoperational stage, the concrete operation stage and the formal operational stage (Boeree, 2004, Campbell, 2002, Gruber & Voneche, 1995 and Sprenger, 1999). The sensorimotor stage begins at birth and lasts until about age two years. The infant learns about the world using senses and motor abilities that are produced with innate reflexes. An example of an innate motor skill is the sucking response. Actions are not internalized in the form of thought. For most of the stage, objects that are not visible do not exist for the infant. By the end of the sensorimotor stage, an infant can solve sensorimotor problems such as reaching objects (Boeree, 2004, Campbell, 2002, Gruber & Voneche, 1995).

From approximately age two to seven years, the child is in the preoperational stage. Symbolic function develops which allows understanding of language and the ability to speak. The child begins to play creatively as the process of mental imaging develops. This allows internalization of actions into thought. There is also an understanding of the past and future. A child at this stage is also egocentric; he can see only his own point of view (Boeree, 2004, Campbell, 2002, Gruber & Voneche, 1995).

The third stage of development, the concrete operational stage lasts from age seven to eleven years. At this point the child can think logically as long as the situation is concrete. The best indicator that a child has reached this stage is the ability to conserve number, length and liquid volume. The child understands that the amount of matter stays the same even if its form changes. Reversibility is possible also; the object can be returned to its original form. The child develops the operational systems of classification and seriation. Seriation is putting things in order or showing linking relationships. This is only done at a concrete level and through handling materials. The relationship between cause and effect, or causality, occurs in the physical world as well (Boeree, 2004, Campbell, 2002, Gruber & Voneche, 1995).

Thought processes move from the concrete level to the abstract level in the fourth stage; the formal operational stage, which begins at about age eleven years and continues through adulthood. There are five important transformations from the concrete operation stage to the formal operational stage. The most important transformation is gaining the capacity for reasoning about a hypothesis. The child is able to verify hypotheses and show actual relationships. This is the same process used by scientists to make hypotheses, predict the consequences and make observations to see if the expectations are met. Experimentation can be done in an organized fashion, exploring all possible combinations of factors in a logical sequence (Campbell, 2002, Gruber & Voneche, 1995). Additional factors within the experiment can be discovered and explored as well, since the child's logic is now concentrated on propositions as objects. For example, in an experiment about the movement of balls of different masses on a horizontal surface, students may suggest that factors such as friction or air resistance will affect the motion (Campbell, 2002, Gruber & Voneche, 1995).

The use of propositional logic is the second transformation. In the concrete operational stage, the child reasons using a process that Piaget called intrapropositional operations, such as classes, numbers and relations. This ability changes to interpropositional operations when the child reaches preadolescence. The child can determine the validity of a train of thought independently of its factual content. This leads to the ability to discriminate form from contents and use symbolic logic. The change from intrapropositional operations to interpropositional operations is the third transformation. The fourth transformation is the ability to combine operations in more complex fashions; forming a closely knit system which allows one element of the structure to pass to another part of the structure easily. The fifth transformation into the formal operational stage enables the child to insert real cases into all possible cases that are logical (Gruber & Voneche, 1995).

Piaget's work is not as simplistic as just the operational stages. He also explains a mental structure called the INRC that produces the five transformations just described. In this structure there are four operational groups; identity (I), negation (N), reciprocity (R), and correlative (C) or dual operations. The parts of the group are combined in a system called the lattice structure. This structure is influenced by reversibility. The two types of reversibility are inversion and reciprocity. Inversion, also called negation, occurs when one action cancels out another action. An example would be pouring water from one container into another container (direct operation) and then pouring the water back into the first container (reverse operation). Reciprocity occurs when considering the combination of direct operations and their reverse results. This shows equivalence such as in 4 x 2 = 2 x 4. Relationships are distinguished with this process. Coordination of reversibility, which is not possible in the concrete operational stage, allows the INRC group to provide a formal structure for the domain of knowledge (Gruber & Voneche, 1995).

In addition to INRC, Piaget's work includes a description of the processes of assimilation and accommodation. Assimilation is the use of the external environment to build schemata (also called schemes or schemas) (Boeree, 2004, Campbell, 2002, Gruber & Voneche, 1995). Schemata are certain skills that direct the way an object in the environment is explored. These skills may be hereditary or acquired. As knowledge is gained, the skills become more sophisticated. In assimilation, a new object fits into the old schemata since the process is conservative and subordinates the environment. If the object doesn't fit into the schemata, then the schemata must be changed in a process called accommodation. In this situation, the individual must change to meet the environment. Assimilation and accommodation are in opposition to one another; the two sides of adaptation or learning. A learner oscillates between the processes to understand the world. An ideal balance between the two processes produces equilibrium (Boeree, 2004, Campbell, 2002, Gruber & Voneche, 1995). The idea that information is assimilated and used to produce schemata is still supported in current research with the concept of prior knowledge and its importance in learning.

Constructivism

Constructivism is a learning theory that describes learning as an active process which uses experiences from the environment to build or construct knowledge and skills. The knowledge is built from within using a thought process, such as reflection, or through social interactions (Llewellyn, 2002 and Staver, 1998). This construction of knowledge and skills is accomplished according to the prior knowledge and understanding. This theory is based on the premise that people search for and construct meaning from the environment by reflecting on our experiences which results in mental models that provide meaning to our experiences (Llewellyn, 2002). Students build new knowledge and understanding on what they already know and believe (Bradsford et al., 2000). In the science classroom, the teacher recognizes that the student is an active participant in the learning process. Prior knowledge may include naïve conceptions or misconceptions. A constructivist teacher will provide experiences that not only allow the students to share their theories but to test their understanding within group activities and inquiry-based investigations (Llewellyn, 2002). In a constructivist classroom, students are provided the opportunity to engage in interactions with the environment to create meaning from the experience. If the experience matches the student's prior knowledge, then the information will be assimilated into the existing understanding. If it does not match, then disequilibrium will result. The student will have to decide to discard the information because it does not fit into the existing schemata or make accommodations to replace the existing schemata with the new information (Bradsford et al., 2000 and Llewellyn, 2002).

Learning Principles

The key findings of the research as described by the National Research Council in "How People Learn" (2000):

1. Prior knowledge must be engaged before new learning can occur.
2. To develop competence in a particular area, the learner must have a deep foundation of factual knowledge, understand the conceptual framework for the facts and ideas and organize the knowledge in ways that aid retrieval and use.
3. Students take charge of their learning through the process of metacognition. In this process they define their goals and monitor their progress. Metacognitive strategies must be taught.

Prior Knowledge

Learning is promoted by the child's genetics and interaction with their environment. Developmental processes strengthen the capabilities that are needed and lose those that are not.

Cognitive changes occur not from a collection of facts, but as a process of conceptual reorganization. There are several early cognitive abilities that are related to learning (Bradsford et al., 2000).

Young children are pre-disposed to learn certain types of information rapidly and readily. They actively engage in trying to make sense of their environment. These areas are called "privileged domains." The areas of information include physical and biological concepts, causality, numbers, and language. While young children lack knowledge, they do have the ability to reason using their current level of understanding. They are curious, which allows them to generate questions. The questions are used to aid in the problem-solving process. Success motivates the child's persistence. Children develop their own metacognition early in life. This gives them the ability to plan and monitor their success. However, children still require assistance from adults who will give them direction and structure. Adults should also regulate the complexity and levels of difficulty. Adults help learning by addressing the needs of the child based on zones of proximal development. This zone is the distance between the child's actual developmental level and the level of potential development. This is determined through problem-solving activities completed under adult guidance or through collaboration with more advanced peers. The zone of proximal development is continually changing while it identifies the upper levels of competence (Bradsford et al., 2000). As the brain develops, different parts of the brain may be ready to learn at different times. This may produce spurts that are similar to Piaget's cognitive development stages (Bradsford et al., 2000).

Smooth transfer of information from neuron to neuron depends on myelination. The growth stages and myelination of the brain appear to match Piaget's four stages of child development. From birth to 2 years, the areas of the brain that grow are the large motor system and the visual system. This matches the sensorimotor stage. During the pre-operational stage, ages 2-7, the language areas of the brain are growing. The parts of the brain that manipulate thoughts and ideas grow during the concrete operations stage for ages 7-11. The largest release of myelin may occur during adolescence, as the area of the brain used for higher-order thinking grows. This coincides with the formal operations stage at ages 11-15 (Sprenger, 1999).

Memory

The activation of several brain systems is the biological event called memory. To be remembered, information must be encoded and processed by neurons (Wesson, 2002b). Jenson (2000) provides a summary of the memory process.

"1. We think, feel, move and experience life (sensory stimulation).

2. All experiences are registered by the brain.

3. They are prioritized by value, meaning, and usefulness by brain structures and processes.

4. Many individual neurons are activated.

5. Neurons transmit information to other neurons via electrical and chemical reactions.

6. These connections are strengthened by repetition, rest, and emotions. Lasting memories are formed." (Jenson, 2000, pg. 215)

The brain has the ability to process many different stimuli simultaneously and interconnect them. Our senses provide the input from our environment. The brain receives information that is conscious and unconscious. Changes in light or body posture can be detected as peripheral perception (Caine and Caine, 1991). 80% to 90% of all information absorbed by the brain is visual so the brain is attracted to movement, contrast, and color changes. The brain also is impacted by aromas and music (Jensen, 2000). Even as babies, humans have the ability to interact with the environment (Sousa, 2006).

An unexpected stimulus focuses the brain's attention, so the brain seeks novelty (Edelman, 2004, Sousa, 2006 and Sprenger, 2007). The more novel or challenging a stimulus is, the more likely that it will activate a new neural pathway (Jensen, 2000). Sight, hearing, and touch provide the most stimuli. A temporary stimulus will cause a neuron to fire once and then the memory will decay (Sousa, 2006). While most responses are based on survival, such as breathing and eating, even an infant will look for patterns. The brain continues to develop as its ability to respond expands (Caine and Caine, 1991). Information that is not meaningful will get less priority and will leave a weaker trace (Jensen, 2000). This creates a perception or recognition that fades quickly. Loss of this type of memory keeps the brain from becoming too cluttered (Sousa, 2006). In the theory of neural group selection (TNGS), memory is a change in the synaptic strength within a neural circuit. This gives the brain the ability to repeat or suppress a specific mental or physical act. Yet, memory is more complex than just a synaptic change. It is a system property in which the context and the association of several circuits with a similar output are affected. So each memory or event is dynamic or changing and context-sensitive (Edelman, 2004). Memory has three stages. Short-term memory is composed of the immediate memory and the working memory. The third stage is long-term memory (Marzano, 1998 and Souse, 2006).

Most stimuli go to the thalamus, which is part of the limbic system that acts as a perceptual or sensory filtering system (Sousa, 2006). The brain processes about 40,000 bits of data per second. This data is sorted by specific traits and characteristics (Sprenger, 1999 and Wesson, 2001). Only the important information is allowed through. The thalamus sends the information to the appropriate area of the cerebral cortex (for example, audio is sent to the auditory cortex). The information is then acted upon or stored. If it is emotional, then it is sent to the amygdala. If it is factual, it is sent to the hippocampus (Sprenger, 1999). The information that makes it through the filter enters the short-term memory. The immediate memory holds information for about 30 seconds. (Sousa, 2006, Hardiman, 2003, Jenson, 2000, Sprenger, 1999 and 2007, and Wesson, 2001). It reacts to threats to survival or emotions, both of which take priority in reacting. Emotions can enhance memory (Sousa, 2006, Jenson, 2000, Sprenger, 1999 and 2007, and Wesson, 2001). Without emotional “arousal”, the stimulus goes unnoticed. Too much emotional “arousal”, causes tension, anxiety and unproductiveness (Jenson, 2000). Hormones that strengthen memory stimulate the amygdala, the part of the brain than controls emotion (Sousa, 2006). The amygdala is responsible for bringing emotional content to memory. The result is that emotion gives memory meaning (Jenson, 2000, Sousa, 2006, and Sprenger, 1999).

The networks that process emotions link the limbic system, the pre-frontal cortices, and the brain areas that map and integrate signals from the body. This speeds up thinking (Jenson, 2000). The ability to focus on information, or learn, is determined by emotion (Wesson, 2001 and Sprenger, 2007). Learners tend to focus on events that have a positive emotional connection because the amygdala is involved in emotions as well as recall and retention (Wesson, 2002a). A positive classroom environment can make a difference in a student’s ability to learn (Hardiman, 2003 and Souse, 2006). Emotions in the classroom should be dealt with gently and personally. Negative emotions need to be processed and positive emotions should be celebrated (Jenson, 2000).

The working memory processes information that is temporary and under conscious control. The information can come from a sensory stimulus or from the long-term memory. New learning occurs in the working memory. The new information stimulates the hippocampus to access the long term memory to find past learning that is similar to or associated with the new information. If this is found, then the networks are activated, the memories are reassembled and are moved to the working memory (Sousa, 2006). A central control mechanism in the short-term memory manages the interaction of visual and spatial codes, auditory signals and information from long-term memory. Sousa (2006) suggests that auditory and visual rehearsal during learning raises the probability that the information will be stored in long-term memory (Hardiman, 2003 and Souse, 2006). For example, listening and reading are used to decode words, phrases and sentences, and put them into the working memory where they can activate prior knowledge (storage and retrieval category) and be processed by the information processing category. Writing and speaking activate prior knowledge first and then encode the information so that it can be expressed by the individual (Marzano, 1998).

There are limits to the number of items that can be held in the short-term memory. Sprenger (1999) explains that there is one memory space at age 3. Every other year another space is added until the age of 15 (Sprenger, 1999). This means that preschoolers can hold only two items. Preadolescents can hold three to seven with an average of five items. Adolescents and adults can hold five to seven with an average of seven items. The average is greater here because of the ability to connect information together in larger pieces through a process called chunking (Sousa, 2006). As a person makes observations, the brain assigns understanding when meaningful patterns are perceived. Familiar patterns can be "chunked" (Caine and Caine, 1991, Bradsford et al., 2000 and Sousa, 2006). Chunking increases the number of items that can be handled by the brain at one time because it views a set of data as a single item. The more an individual can chunk information, the easier it is to recall the information. Experts have organized conceptual structures called schemas that allow them to chunk information more easily than novices. Students must be taught how to recognize meaningful patterns so that chunking can be accomplished (Bradsford et al., 2000).

Chunking occurs in one of two ways. It may be deliberate or controlled by the learner because the learner controls the associations that are chunked. An example is rehearsing a poem one line at a time. The chunking may occur automatically as it is linked to perceptual processes.

An example is the ability of the brain to expand reading processes from recognition of letters to words to phrases and then to sentences (Sousa, 2006). Problem-solving requires chunking because a large amount of relevant information is needed for problem-solving. Experts are better at problem-solving because their knowledge base is more organized and the chunked patterns allow them to be more intuitive (Sousa, 2006). Chunking helps the learner make associations that establish meaning. "Knowing more" infers that there are more conceptual chunks in the memory. There also are more interactions between those chunks. The chunks can be retrieved from memory easily and there are procedures in place to use the chunks in problem-solving (Bradsford et al., 2000). While there is a limit to the number of chunks that the brain can handle at one time, there doesn't seem to be a limit on the amount of information in a single chunk. (Sousa, 2006)

Information in short-term memory will not be remembered unless it is stored in the brain permanently. The brain does not passively record the information from our environment. It works actively to store and recall the information (Bradsford et al., 2000). Sprenger (2007) describes this process in seven steps. The first step is to grab the student's attention with emotion, novelty, or interaction of some other hook. Next, the student must have time to reflect. This could be considered the first rehearsal for the information. Journaling, talking in small groups, and drawing are examples of strategies that can be used for this process. This takes the information to the working memory. The third step is recoding. In this step, the student describes the information in his own words. This increases the level of understanding. The fourth step is reinforcement which employs feedback. The information is still in the working memory and it is imperative to know that the understanding is correct before placing it in long-term memory (Sprenger, 2007). The best feedback is immediate, positive and dramatic. Feedback does not always have to be from the teacher. Trial and error can teach the brain to avoid "bad choices" (Jensen, 2000).

The fifth step is rehearsal. The student must use the information. This can be done with the learning styles of the individual students in mind. The more areas of the brain the information is stored in, the more easily it will be retrieved from the long-term memory. The sixth stage is review. This should be done throughout the unit and for the entire year if standardized testing is done. Review provides feedback and helps students focus on learning. It allows information in long-term memory to be retrieved, manipulated and re-stored in the brain in various formats. The last step is retrieval. The ability to take information from the brain is greater if the other six steps have been completed (Sprenger, 2007). The process of storing and retrieving the information is called long-term memory. Long-term storage is the area of the brain where memories are stored (Sousa, 2006).

In order for information to be stored in long-term memory, it must meet two criteria: It must make sense or form patterns and it must be perceived as meaningful or important (Jensen, 2000, Sousa, 2006 and Sprenger, 1999). If the information has survival value, then it is stored more quickly. For example, the memory of touching a hot object is stored more easily (Sousa, 2006). Information will only be meaningful if survival needs are met first (Jensen, 2000). Of the two criteria, meaning, which is personal and influenced by past experience, is the most important (Sousa, 2006). Several factors influence meaning-making. The first is relevance. This occurs when the brain makes a connection with existing neural sites. The second is emotion, which is triggered by the brain's chemicals, indicating that learning is important. The last is context, which triggers pattern making. Patterning is the "meaningful organization and categorization of information" (Caine and Caine, 1991, pg 81). Patterns activate larger neural fields. Meaningful learning is generated internally. The brain looks for links, associations, uses and procedures. This means that reflection time is required. More intense new learning needs more reflection time. Meaning is produced when the information is personal, there is an emotional attachment and it makes sense (Jensen, 2000).

When the information has meaning, the hippocampus encodes the information and sends different parts of the memory to various sites in the brain for storage. The division of the different parts of the memory allows the brain to process large amounts of experiences using cells linked to similar network systems (Wesson, 2001). If the stimulus repeats the pattern of firing, then the stimulated neurons will bind together and fire simultaneously. This makes retrieving the memory easier (Sousa, 2006). Retrieval is easier because as information arrives in the cerebral cortex, the brain will match each trait or characteristic to previously stored information of a similar type. If the information finds a match, then the event is "recognized" (Wesson, 2001). Repeating an event or activity, causes the same neurons to fire and strengthen their connections. This leads to the saying, "Neurons that fire together, wire together" (Wesson, 2001, Sprenger, 2007, and Edelman, 2004). Any incoming data that does not find a match does not register in the brain so the neurons do not respond in a meaningful way. This is the reason that activating prior knowledge is so important for educators (Wesson, 2001).

The brain's ability to store information is unlimited. However, storing information, or memory, is not the same as learning. Learning is a process in which a person acquires new knowledge and skill. Memory is the process of retaining the knowledge or skills for future use (Sousa, 2006).

Retention

Learning also is not the same thing as retention. To learn, one acquires new information and skills through a process of interplay between the brain, nervous system and environment. It does not necessarily include long-term retention. Retention requires the construction of conceptual frameworks that make sense and have meaning so that they will be stored in long-term memory. In this way, learning is preserved so that it can be located and retrieved accurately (Marzano, 1998 and Sousa, 2006). Retrieval of memories is the only evidence we have that learning has occurred (Sprenger, 1999). Retrieval triggers memories by activating enough of the right neurons which are dormant. Each type of learning or memory has its own type of triggering system (Jensen, 2000). In order for information to be retained, rehearsal must occur (Caine and Caine, 1991, Sousa, 2006 and Sprenger, 2007). Rehearsal is the repetition and processing of information. (Practice is repetition of motor skills.) The critical components of rehearsal are the amount of time spent and whether the type of rehearsal is rote or elaborative (Souse, 2006).

During initial rehearsal, time must be spent on attaching meaning and making sense of the information. Time must be given for additional processing or the new information will be lost. Secondary rehearsal occurs in the frontal lobes. The material is reviewed, sense is made of it, there is elaboration of details, and values and relevance are assigned. When secondary rehearsal is done at the end of learning, the process is called closure. Rehearsal occurs at different rates of speed and in different ways depending on the type of information and the student's learning style. Different tasks can also shift the pattern of rehearsal (Souse, 2006).

Rote rehearsal is memorizing which is linear in nature (Caine and Caine, 1991). The information is stored exactly as it is entered into the working memory. Examples would be memorizing a poem or telephone number. Elaborative rehearsal requires attaching the new learning to prior knowledge and finding a relationship between them. The information is reprocessed several times so that connections can be made and meaning can be assigned. This produces understanding that rote rehearsal does not provide (Souse, 2006).

Retention also depends on when the information is included in the learning cycle. According to the primacy-recency effect, we remember best that which comes first (prime time 1), and second best that which is last (prime time 2). We don't remember the information in the middle as well (Sousa, 2006). This is also called the BEM Principle. The beginning is most memorable. The end is second most memorable and the middle is remembered last (Jensen, 2000). During prime time 1, which is about 20 minutes long, working memory is filled to capacity. Any excess information is lost. This time is called down time and lasts about 15 minutes. As learning continues the working memory sorts and chunks the important information and clears out the unimportant information making room for the information in prime time 2, which lasts about 15 minutes. It is important then, that information stated during prime time 1 is stated correctly. Student answers which may be incorrect could actually be stored in the memory.

It would be better to do practice or review activities during down time. Closure activities during prime time 2 help to determine sense and meaning (Souse, 2006).

Retention also varies with the length of the teaching episode. As the time for the lesson increases, the amount of down time also increases because the working memory cannot sort and chunk fast enough to keep up. Teaching methods also influence retention. The learning pyramid from the 1960's (seen in Figure 2.2) indicates that the amount of retention after 24 hours (Souse, 2006). In the verbal processing skills, lecture retains 5% and reading retains 10%. In the verbal and visual processing skills, audiovisual retains 20%, demonstration retains 30%, and group discussion increases retention to 50%. In the doing section of the pyramid, practice by doing retains 75% and teaching others or immediate use of learning retains 90%.

Figure 2.2 1960's Learning Pyramid (Sousa, 2006)

Verbal	Lecture	5%
Processing	Reading	10%
	Audiovisual	20%
Verbal and	Demonstration	30%
Visual Processing	Discussion Group	50%
	Practice by Doing	75%
Doing	Teach Other/Immediate use of Learning	90%

If a concept is taught several ways (do it, hear it, see it, write it), it will be easier to recall. It often takes six exposures before new information enters long-term memory, so it is better to combine multi-sensory with multi-modal approaches to reach a learner's learning preference or cognitive learning style (Wesson, 2002b). Successful teachers know that there is not a "best" teaching method. They use a variety of methods during a lesson choosing the one that works for the content being taught and the students' needs. Most importantly, student must be actively engaged in whatever method is being used (Sousa, 2006). The ability to remember is influenced by the manner in which the information was encoded. A learner will remember more easily if retrieving the information uses the same techniques as was used to encode it or if it has an emotional connection. Ineffective initial encoding can cause poor memories. For example, when given the task of choosing the one correct picture of a penny from a group of ten pictures, most people choose incorrectly. They do not have a personal connection. However, coin collectors, who have a personal connection, usually choose correctly (Wesson, 2002b). Once retained in the brain, a memory must be retrievable. Retrieval, which comes from long-term memory, activates separate neural systems of the brain. The interests and past experiences of the learner influence the types of cerebral network that contains the memory.

Retrieval has two methods. In recognition, the information is matched with memories that are stored. In recall, events are sent to long-term memory which searches, retrieves or encodes the memories to the working memory (Sousa, 2006). Memories are distributed though the cortex. Sound is in the auditory cortex. The temporal lobe contains names, nouns and pronouns. Emotional events and implicit memories are in the amygdala. The cerebellum holds associative memories and motor skills. Explicit memories and special memories are in the hippocampus. The brain must reconstruct the various elements of an event (Jensen, 2000).

Since the memory must be reconstructed, the adequacy of the cues affects the retrieval process. Retrieval is easier if the context of the memory is similar to the context of the learning. The rate of retrieval is linked to the storage method used by the learner. This is a learned skill, which is completely independent of the rate of learning (Sousa, 2006). To retrieve a memory, it must be brought back to the corresponding area of the cortex (Sprenger, 1999). Memory retrieval is aided by the introduction of multiple methods of learning or multiple memory lanes. Important events will trigger more than one memory lane. Retrieving the information will be easier if one of the memory lanes is activated. For example, returning to a particular location will activate episodic memories. Recalling an emotional event can open all the other memory lanes. This translates to the use of emotion in classroom learning. If a memory fails, a systematic examination of each memory lane may help to retrieve the information (Sprenger, 1999).

Transfer

The most effective learning occurs when a student is able to take new information and adapt it for new problems and settings. The ability to use learned information in a new situation is called transfer. Transfer is a process that occurs during learning. Past learning affects the way new information is processed and acquired. Transfer of learning also occurs when new information is applied in future situations. If we must learn to function in society, then what we learn must be transferred to home, community and workplace. An assumption that has been made about transfer is that people should be educated and not simply trained (Bradsford et al., 2000).

The more information students can transfer from school to the context of daily life, the better they will be at communicating. They will be informed citizens who are critical thinkers and problem-solvers. (Sousa, 2006) "Transfer is the core of problem-solving, creative thinking and all other higher mental processes, inventions, and artistic products." (Sousa, 2006, pg. 135)

Transfer is influenced by several factors. The first factor is initial learning or the degree of mastery of original context. The learner must understand – not just memorize- the information. This takes time which is roughly proportional to the amount of material being learned. Providing time includes the time needed to process the information. Covering too much information too quickly will reduce transfer because the facts will be isolated rather than organized and there is not enough information to make the organizing principles meaningful. The time provided for learning should include deliberate practice combined with monitoring of the learning experience (Bradsford et al., 2000).

The second factor that affects transfer is context. Information may be learned in one context but not another. Transfer across contexts is more difficult when a topic is taught in a single context rather than multiple contexts (Bradsford et al., 2000). Transfer is better with thematic units and integrated curriculum. The more connections the learner can make, the more meaning the information will achieve. This causes an increase in retention (Sousa, 2006) Transfer is better if the learner is lead to problem-solving at a higher, more abstract level. The abstract representations become components in schemata of related events. This allows the learner to observe similarities and differences. The schemata lead to more complex thinking such as analytical reasoning. Schemata combine related events rather than looking at each event individually. This improves retrieval and transfer of information (Bradsford et al., 2000). "The transfer literature suggests that the most effective transfer may come from a balance of specific examples and general principles, not from either one alone." (Bradsford et al., 2000 pg 77)
The third factor that effects transfer is the idea that it is an active, dynamic process. This allows the learner to choose and evaluate learning strategies and resources. Learners can also assess readiness for tests and performances. Feedback is a critical part of this process. When students become more aware of themselves as learners – use their metacognitive skills – transfer increases and uses less prompting (Bradsford et al., 2000).

The fourth factor is transfer of previous learning. Initial learning requires transfer of previous knowledge brought to the learning situation. Teachers should activate this knowledge and build on to it (Bradsford et al., 2000). Mental images or conceptions that students have may have come from daily experiences. When these representations do not align with the scientific point of view they are called misconceptions (Duit and Treagust, 1995). Misconceptions in the prior knowledge may cause a misinterpretation of the new information, so teachers must also address the misconceptions. Learners will also need the teacher's assistance to connect the information to everyday life. It is important for teachers to remember that prior knowledge comes from a variety of sources. The personal experiences of each student are unique. There is a set of generic experiences from developmental stages that all students share. Knowledge is also impacted by social roles that are influenced by race, class, gender, cultural and ethnic affiliations. Transfer is improved when information is attached to cultural knowledge (Bradsford et al., 2000).

If the past learning helps with the new learning, then the transfer is positive. An example would be a trumpet player learning to play the tuba easily. If the past learning interferes with the new learning, then the transfer is negative. An example would be learning to drive a vehicle with an automatic transmission first. Learning to drive with a standard transmission is then more difficult (Sousa, 2006). Students must cross a sufficient threshold of learning so that understanding occurs. This level of understanding takes time for deliberate practice and feedback. Higher understanding translates to more transfer (Bradsford et al., 2000).

Transfer is also influenced by the context in which the material is taught. Teaching within a single context limits transfer of the information. Using a variety of contexts allows flexibility and greater transfer. This flexibility increases when students learn how to extract underlying themes and principles to aid in problem-solving. Teachers should emphasize organized, "coherent" bodies of knowledge, help the student learn how to transfer information and help students use what they learn. Transfer of learning, like learning itself, is an active process. It may require a chance to learn more about the new situation before transfer can occur (Bradsford et al., 2000).

Transfer of previous experiences is involved in all learning. Prior knowledge and experience affect how a learner looks at the environment and how the new information is interpreted and organized. This, in turn, affects the ability to remember, reason, problem solve and acquire new information. As stated earlier, transfer can be either positive or negative. Teachers should be cognizant of misconceptions and incomplete explanations. These should be built on in such a manner that they become more accurate (Bradsford et al., 2000).

Metacognition

The conscious process of learning is metacognition. Metacognition is a self-regulation process that allows a learner to plan, monitor success and correct errors while learning. This ability develops gradually and is influenced by knowledge and experience (Bradsford et al., 2000). The metacognitive system provides strategies or plans for "execution" of problem-solving skills. As a result, it controls the knowledge domain and the cognitive system. It consists of four components. The goal specification component determines when a task has been finished. The process specification component finds and activates the skills, tactics and processes needed to achieve a specific goal. It designs a new process that is "strategic in nature" for every new task. This requires conscious thought. The process monitoring component evaluates the effectiveness of the algorithms, tactics and processes to insure optimal effectiveness. Another component that requires conscious thought is disposition monitoring. This component relates the individual to focus on a task by influencing clarity, accuracy and precision and impulsivity (Marzano, 1998).

Through a series of learning processes, a learner becomes more proficient in a particular content area – evolves from a novice to an expert. Expertise is achieved by mastering the content. Information is not memorized as isolated facts. Understanding of the information is reflected by the organization patterns or conceptual structures which in turn reflect the context of applicability. Expertise is influenced by several factors. The information is easier to organize if it is relevant. Experts can access relevant information more quickly because it is organized around important concepts in such a way that patterns, relationships and discrepancies are evident. Novices are not able to distinguish between usable knowledge and less organized knowledge. As a result, they will not recognize the potential relevance of new tasks or information, which the expert does easily. Experts can then use the knowledge to make inferences from problems representations. The different types of representations for a particular problem can influence the ease with which the problem is solved – or not. Experts solve sophisticated problems more readily because the knowledge is well organized which makes it more accessible (Bradsford et al., 2000).

Different organizing properties are used in different domains of knowledge or content areas. Each content area has its own information and organizational structure. Learners should monitor and regulate their own processing and change strategies when necessary. The ability to monitor the level of understanding and make adjustments is called metacognition. It requires self-assessment and time for reflection. A coherent understanding of the organizing principles in the content area will produce effective comprehension and thinking. Learners perform tasks in specific contexts because their competences are supported by sets of tools and social norms (Bradsford et al., 2000).

Brain-based Learning

Learning the way the brain is naturally designed to learn is called brain-based learning. This theory describes learning with the brain in mind; with the knowledge that the brain is adaptive (Jensen, 2000). Brain-based learning is also called "brain-compatible learning." It explores how learning occurs through an integration of factors such as prior knowledge, emotions, physical needs, attitude, interdisciplinary thinking, expectations and culture (Benjamin, 2002). The learning is multidisciplinary and does not follow a prescribed formula. An example of this occurs when a child's learning is scattered or random as the child explores and manipulates the environment (Jensen, 2000). The brain operates on many levels of consciousness by processing color, motion, sound and other stimuli all at one time. Teaching then, should not be structured in a linear direction. The processing also attaches emotions and forms patterns of meaning that allow the construction of the larger picture and allow inferences to be used to make conclusions (Jensen, 2000). This learning theory is described by Caine and Caine (1991) using twelve principles that are shown in Figure 2.3

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Figure 2.3 Twelve Principles of Brain-Based Learning (Caine and Caine, 1991)

1. The brain is a parallel processor.
2. Learning engages the entire physiology
3. The search for meaning is innate.
4. The search for meaning occurs through "Patterning."
5. Emotions are critical to patterning.
6. The brain processes parts and wholes simultaneously.
7. Learning involves both focused attention and peripheral perceptions.
8. Learning always involves conscious and unconscious processes.
9. We have at least two different types of memory: a spatial memory system and a set of systems for rote learning.
10. We understand and remember best when facts and skills are embedded in natural, spatial memory.
11. Learning is enhanced by challenge and inhibited by threat.
12. Each brain in unique.

Most of these principles have been addressed in the previous explanations of memory. The terms used for memory in the twelve principles such as spatial memory is different but the information aligns with short-term and long-term memory previously discussed. A complete discussion of the twelve principles must include the influence of emotion on learning and the uniqueness of the brain.

Each brain is unique (Caine, and Caine, 1991, Jenson, 2000, Sousa, 2006 and Sprenger, 2007). Factors that influence the brain are both genetic and environmental (Jensen, 2000). The interpretation of environmental stimuli is different for each individual. "The more we learn, the more unique we become." (Caine and Caine, 1991, p. 87) The brain is a dynamic organ that is shaped by its experience (Bradsford et al., 2000) and its development is on its own individual time-table (Jensen, 2000). Learning physically changes the brain by altering the electrochemical wiring of the neurons. (Jensen, 2000, Bradsford et al., 2000, Sousa, 2006, Edelman, 2004, and Sprenger, 2007). Storing information creates new pathways or strengthens the old ones (Sousa, 2006). The connections produced between neurons form a personal cognitive map. The neural network communicates with each other in such a way that more connections will produce greater meaning from the learning (Jensen, 2000). The brain combines the information in a unique way. This influences how we see the world – our cognitive belief system. Our self concept, or the way we see ourselves, is influenced by emotion and past experiences. (Sousa, 2006)

Brain changes are caused by three factors; intrinsic forces, experience expectant processes and experience dependent processes. The genetic pre-wiring processes of the brain are called intrinsic forces. These produce a template for processes that change the brain. Experience expectant processes cause the brain to create an overabundance of synapses before they are needed. This occurs when all members of the species need that particular learning. It relies on the fact that certain events will occur at a particular time. Experience dependent processes are triggered by environmental stimuli (Jensen, 2000).

The brain is influenced by diet, sleep and exercise. The brain cannot store energy, yet it uses lots of energy, so breakfast is essential. This meal should include protein, fat, starch and sugar. Sleep deprivation has a negative effect on brain function. In addition, sleep is needed for processing information. During sleep, the brain disposes of unneeded trivia, practices new information and regulates emotions. An individual should exercise 30 minutes for 3-4 days a week. This increases the oxygen to the brain which helps the brain to excrete waste products. It also increases blood flow to the brain which encourages neurogenesis (the growth of new neurons). Exercise also reduces depression. All of these cause better memory function (Sprenger, 2007).

Learning Taxonomy

Bloom's taxonomy for both cognitive and affective domains was first published in 1956. At the time, the domains changed the way educators viewed learning (Marzano, 1998). The six levels of processing showed that different types of learning required different types of thought (Marzano, 1998). Bloom's taxonomy is familiar to most teachers. It not only provides common language to describe learner objectives, but distinguishes relationships between the difficulty and complexity components. Complexity describes the thought processes used by the brain to "deal with" information. Difficulty is the amount of effort the learner applies within a level of complexity. The taxonomy is easy to implement and is inexpensive because it does not require additional classroom materials. It motivates teachers because they can observe their students learning better, thinking insightfully and showing more interest. The taxonomy has six levels of complexity .The six levels of processing show that different types of learning are required for different types of thought (Marzano, 1998). In the knowledge level, the learner has the information. At the comprehension level, the learner understands the information. As the learner uses the information, the application level is achieved. When the learner can separate the components of the information and then put them back together, analysis is complete. During synthesis, the learner brings together "disparate" information. Evaluation occurs when the learner uses specific criteria to make judgments (Benjamin, 2002).

It now seems that the processes, however, were oversimplified. A learning taxonomy shows a linear relationship that is hierarchical in nature. Learning is not linear and the levels in Bloom's taxonomy do not always build upon one another. Marzano proposes that the taxonomy should be replaced with a learning theory. A theory predicts behavior for specific situations and it represents a flow of data with the learning situation. The process always starts with self-system, goes through the metacognitive system, proceeds through the cognitive system and finishes in the knowledge domain (Marzano, 1998).

While Marzano would replace Bloom's taxonomy with a learning theory, Shulman proposes a "Table of Learning." This table also has six levels; engagement and motivation, knowledge and understanding, performance and action, reflection and critique, judgment and design, and commitment and identity.

"In a nutshell, the taxonomy makes the following assertion: Learning begins with student engagement, which in turn leads to knowledge and understanding. Once someone understands, he or she becomes capable of performance or action. Critical reflection on one's practice and understanding leads to higher-order thinking in the form of a capacity to exercise judgment in the face of uncertainty and to create designs in the presence of constraints and unpredictability. Ultimately, the exercise of judgment makes possible the development of commitment. In commitment, we become capable of professing our understandings and our values, our faith and our love, our skepticism and our doubts, internalizing those attributes and making them integral to our identities. These commitments, in turn, make new engagements possible – and even necessary" (Shulman, 2002. Pg. 38). In this fashion, the taxonomy becomes a cycle because committed people tend to be more engaged. Because these levels may interact in other ways, it is possible to flow in multiple directions. In fact, Shulman suggests that taxonomies should not just be followed, but should be "played with." As with cycles, the order through which the learner travels can vary. Instead of being hierarchical or linear, the Table of Learning is heuristic or interconnected.

Figure 2.4 Modified Bloom's Taxonomy

Bloom's Original Taxonomy	↑	Revision in 2001
Evaluate		Create
Synthesis		Evaluate
Analysis		Analyze
Application		Apply
Comprehension		Understand
Knowledge		Remember
	Complexity	

There are others that have a different solution to the problems with Bloom's taxonomy. In 2001, a team of researchers and psychologists revised Bloom's taxonomy to reflect the latest research on brain functions as seen in Figure 2.4 (Sousa, 2006 and Sprenger, 2007). The reason for the revision is that thinking is active, so the words that describe the learning process should be active verbs (Sprenger, 2007). The six levels have been renamed using the appropriate verb. Remember is rote recall. To understand is the ability to make sense of the material. The learner can use the information in the future for problem-solving and making decisions. The level called apply uses the information in a new situation. In the analyze level, the information is broken down into its component parts. Relationships between parts and parts and between parts and the whole can be examined. In the evaluation level, the value of the information is determined based on criteria and standards. The learner can consolidate thinking and is receptive to alternate points of view.

The process of evaluation moves down a level because the act of creating (generating and reproducing) requires more complex thought than evaluation (Sousa, 2006). The create level, which replaces synthesis, allows the learner to place parts together in a new way using a divergent thinking process. While the original taxonomy was cumulative, the levels of the revision overlap. "Another approach is to view remember and understand as skills designed to acquire and understand information and apply and analyze as skills for changing and transforming information through deduction and inference. The skills of evaluate and create generate new information by appraising, critiquing, and imagining. Even here, one must remember that the levels are fluid and overlap." (Sousa, 2006, pg 254) The overlapping of levels is important because brain evidence shows that different areas of the brain solve different types of problems. The new version has all the skills of the basic processes of the brain. Remember and understand require observation. Remember, understand and analyze require finding patterns and generalizing skills. Forming conclusions from the patterns is found in analyze and create levels. Assessing the conclusion is found at the evaluation level. (Sousa, 2006)

Teacher Knowledge

The knowledge of a teacher is reflected in the instructional strategies that are used in the classroom. The instructional strategies are determined by several factors; subject matter knowledge, pedagogical knowledge and pedagogical content knowledge.

Subject Matter Knowledge

Understanding subject matter is more than memorizing facts. Teachers must understand how the knowledge is created, organized, linked to other disciplines and used to solve real-world problems. This understanding is critical to the analytical skills that students must learn (NBPTS, 2002). Teachers with subject matter knowledge are better able to go beyond the textbook and involve students in meaningful discussions and student-centered activities (Stronge, 2007) such as discovery learning or problem-solving (NBPTS, 2002). Subject matter knowledge also assists in planning and organizing lessons that are sequential and interactive (Stronge, 2007), using appropriate strategies and instructional materials to provide multiple pathways to knowledge (NBPTS, 2002 and NCTAF, 1996).

Subject matter knowledge or content knowledge is important (Stronge, 2007 and Tobin, Tippins, and Gallard, 1994). Curriculum and pedagogical decisions are influenced by the teacher's knowledge of a subject (Anderson and Mitchener, 1994). Studies that show that student achievement is positively related to the teacher's course taking background in education and content (Stronge, 2007). When the teacher's knowledge is high, there is a greater opportunity to exhibit the knowledge and student knowledge improves as a result (Tobin, Tippins, and Gallard, 1994). Content knowledge includes the factual information as well as concepts, principles, relationships, methods of inquiry and important issues (Danielson, 2007). Teachers must be able to not only explain what a particular concept is but why it is important and how it relates to other concepts as well (Shulman, 1986). Teachers who are more comfortable with the content will allow the students to explore the content in more diverse ways (Tobin, Tippins, and Gallard, 1994). Teacher knowledge can be described using five overlapping categories; conceptual knowledge, subject matter structure, nature of the discipline, subject matter knowledge, and contextual influences on implementation (Gess-Newsome and Ledermen, 1999) or as four dimensions; content, substantive, syntactic and beliefs (Anderson and Mitchener, 1994).

The content dimension, or conceptual knowledge, is described as the facts, concepts, principles, and procedures to be taught (Anderson and Mitchener, 1994 and Gess-Newsome and Lederman 1999). These will be influenced by beliefs, socially constructed, and personally integrated as they are used for problem-solving. The conceptual knowledge of a novice or pre-service teacher, is quite different from that of an expert teacher and this is reflected in the way that they teach. The novice has less knowledge and will give inaccurate descriptions while the expert will be more accurate and have a better repertoire of representations for the content. The novice relies more on the textbook and memorization, talks more, asks lower level questions and in science, conducts labs but the activities will have less exploration. The expert teacher emphasizes the nature of science. Lectures contain new information and higher level questions are asked. There are more open-ended activities so the unit of study will take a longer period of time. The activities used will be chosen because they worked well previously in achieving the intended goals (Gess-Newsome and Lederman 1999). The novice teacher has difficulty deviating from the lesson plans while experienced teachers are more flexible which allows them to adjust to a teachable moment or schedule change (Stronge, 2007).

The substantive dimension, or subject matter structure, is the organization of conceptual knowledge that allows storage and retrieval of information. It can be described as the explanatory framework that guides inquiry in the content field (Anderson and Mitchener, 1994) or a depth of understanding of the subject matter (Shulman, 1987). Teachers tend to think about the teaching of the content rather than the content separately. This is different from scientists who have structures based on laboratory research which allows them to have better connections between concepts. Novice teachers, with limited subject matter structures, can plan only a few days ahead (Gess-Newsome and Lederman, 1999). Knowledgeable teachers know which concepts are central and which are peripheral in nature. They can show the interactions between the concepts (Danielson, 2007). Expert teachers, who integrate the concepts better, see the whole picture and can plan longer into the future. There is not any evidence to show that multiple structures make better teachers (Gess-Newsome and Lederman 1999).

The syntactic dimension aligns with the nature of the discipline. This is described as the understanding of the history, philosophy and sociology of the content. The nature of the discipline determines the questions to be asked, the method used for inquiry, the nature of the discourse and the cannon of evidence to be used (Gess-Newsome and Lederman, 1999). It is the understanding of the processes used to incorporate new knowledge into the content field (Anderson and Mitchener, 1994) because it is the framework which facilitates new understanding (Shulman, 1987). Pre-service teachers in science education are not required to take courses on the history, philosophy or sociology of science. While they have an appreciation for the nature of science, they have no idea how to incorporate this information into their teaching. There are five levels to describe a teacher's understanding of the nature of science. The naïve stage views science as a body of facts. About forty percent of teachers, including novices, are in this stage (Gess-Newsome and Lederman 1999). Teachers in this stage emphasize vocabulary, spend less time on conceptual relationships and spend less time doing lab work. Because they follow the textbook, the "scientific method" is taught only at the beginning of the year – reflecting the arrangement of the text.

As teachers become more knowledgeable, they go through the experimental-inductionist stage, followed by the experimental-falsificationist stage, and then the technological stage. The last and most desirable stage is the three phase process in which teachers illustrate how theories are developed, how theories are tested and how theories are accepted or rejected by the scientific community. Only about four percent of the science teachers are in this stage. However, they are the most effective teachers. They emphasize inquiry-oriented questioning, encourage active student participation, use problem-solving activities and provide a risk free environment that includes support of the desired behaviors. Still, it appears that the teacher's understanding of the nature of science does not have the largest impact on classroom practice. The most influential factors are constraints imposed by administrative policies, classroom supplies, achievement goals, district curriculum and accountability (Gess-Newsome and Lederman, 1999).

"While experienced teachers use teaching techniques that supported student understandings of the nature of science, many of these teachers did not hold explicit goals to teach students the nature of science. In fact, many teachers, despite a high level of understanding of the nature of their discipline, are unsure of how to portray this understanding in their teaching." (Gess-Newsome and Lederman, 1999, pg. 75)

The fourth category of subject matter knowledge is content specific orientation or the beliefs that influence teaching. These direct the orientation toward teaching the content area (Anderson and Mitchener, 1994). Those teachers with weak initial orientation will adopt the orientation of the textbook, curriculum guide or previous coursework. They will look for classroom activities that match that orientation. Constraints for the teacher include required curriculum, standardized tests, parent expectations, student grades and personal views of the content. Teachers who are asked to adopt new pedagogy will return to their old familiar patterns when things become too difficult. The good news is that a lack of understanding in the content area forces teachers to learn their content better (Gess-Newsome and Lederman 1999).

The fifth category is contextual influences on implementation. Teachers will choose materials that match their individual views of teaching and learning. Novice teachers will rely on whatever is given to them. As they become more experienced, they will adjust what they are doing to match their students' needs. The experienced teacher will use those activities that were successful in prior years. The adoption of materials is influenced by a variety of factors; time constraints, subject matter knowledge, orientation, and required curriculum (Gess-Newsome and Lederman, 1999). However, understanding the content is not enough to produce good teaching (Danielson, 2007). Educational coursework has an important positive influence on student learning as well (Stronge, 2007). The content must be transformed into the appropriate activities through instructional planning (Danielson, 2007). The knowledge needed for this transformation is called pedagogy (Anderson and Mitchener, 1994).

Pedagogical Knowledge

Pedagogical knowledge is both general and personal. Personal pedagogical knowledge is influenced by prior beliefs and perceptions. This knowledge changes as the teacher learns how to teach. One factor that changes is the perception of what a teacher does. With increased experience, teachers become more aware of their own knowledge and the knowledge of their students. Teachers become more concerned with student learning rather than surviving the day. Management and instruction develops distinct routines and there is an increase in the number of problem-solving activities (Morine-Dershimer and Kent, 1999). There are several factors that contribute to general pedagogical knowledge: classroom organization and management, instructional models and strategies, and classroom discourse (Morine-Dershimer and Kent, 1999).

Instructional Models and Strategies

Teachers must be able to understand and use the body of generic pedagogical knowledge. This includes a variety of instructional strategies that are adaptable to multiple content areas and their implementation (NBPTS, 2002 and NCTAF, 1996). While implementing these strategies, teachers must set the expectations for the learning environment so that behavior does not interrupt learning (NBPTS, 2002).

Teachers' knowledge use must also take into consideration the student's ability to judge understanding and use their own cognitive strategies during learning. The teachers' perception and understanding of classroom events will influence the learning process as well. As the learning process proceeds, the teacher will use instructional models and strategies to alter the forms of instruction. These alternatives are directed by the learning capacity goals which are based on the content, the type of academic tasks such as direct instruction or scaffolding, and the ability to connect the goals and the tasks which promotes independent thinking by both the teacher and the student. In a learning community, the students are active learners who are self motivated and active. The zones of proximal development are apparent as are the individual differences among the students. There is an active exchange of ideas through dialogue and questioning. Learning and teaching depend on a process of group inquiry which in turn is dependent on the student's developmental level. The assessment fits the intended curriculum (Morine-Dershimer and Kent, 1999).

Table 2.1 Categories of Instructional Strategies that Affect Student Achievement

Category	Ave. Effect Size (ES)	Percentile Gain	No. of ESS	Standard Deviation (SD)
Identifying similarities and differences	1.16	45	31	.31
Summarizing and note taking	1.00	34	179	.50
Reinforcing effort and providing recognition	.80	29	21	.35
Homework and practice	.77	28	134	.36

Nonlinguistic representations	.75	27	246	.40
Cooperative learning	.73	27	122	.40
Setting objectives and providing feedback	.61	23	408	.28
Generating and testing hypotheses	.61	23	63	.79
Questions, cues, and advance organizers	.59	22	1251	.26

Effective teachers have a repertoire of strategies such as those listed in Data Table 2.1. This list was generated as the result of a meta-analysis conducted by Marzano. It lists the strategies based on the effectiveness in the classroom (Marzano, 2003). However, no single teaching strategy works effectively in every situation (Danielson, 2007, Marzano, Pickering, and Pollock, 2001, NSES, 1996, and Stronge, 2007). Instruction should be based on student performance and interest levels to meet affective and cognitive needs (Stronge, 2007). The heart of professionalism is the choice of the teaching strategies (Danielson, 2007). One limitation of Marzano's meta-analysis is that it clumps all content areas together. He acknowledges that some of the instructional strategies may be more effective in different content areas. Strategies from the National Science Education Standards (NSES, 1996) such as student-centered instruction, critical thinking skills and hands-on labs were not included in the meta-analysis (Marzano, Pickering, and Pollock, 2001).

In choosing strategies for the science classroom, a teacher must consider that effective learning requires that students take control of their own learning. Transfer of knowledge is affected by prior knowledge. This translates to the incorporation of strategies that consider four elements; learners, knowledge, assessment, and community. Learner-centered environments are developed with the students' prior knowledge and beliefs in mind. Knowledge-centered environments organize the knowledge in ways that encourage the students to make connections. Assessment-centered environments provide students the opportunity to monitor and regulate their own learning by providing feedback and opportunities to revise their work. Community-centered environments encourage the students to learn from one another by communicating their ideas and challenging those of others (Bradsford et al., 2000).

In order to know the accomplishments of the students, teachers must evaluate their learning, both as individuals and as a class. This requires that the teacher understands the purpose, timing and focus of the evaluation. The results of the evaluation determine the pathway of the class as it proceeds to the completion of its goals (NBPTS, 2002) and the ability to explain student achievement to the parents (NBPTS, 2002 and NCTAF, 1996).

Classroom management and organization

Classroom management and organization includes the classroom arrangement, proactive disciplinary policies, classroom routines which limit disruptions, and a plan to teach the students the organization of their learning environment (Stronge, 2007). The teacher must balance the need to maximize content coverage while achieving student mastery in chunks of information that the student can handle. Teacher behaviors such as structuring new information, relating information to prior knowledge, the monitoring of performance and providing adequate feedback, have a direct influence on student learning. These behaviors must also be adjusted for appropriate grade level, objectives and individual student needs. To maintain appropriate activities, classroom management must provide an efficient use of time combined with clear expectations that are implemented consistently (Morine-Dershimer and Kent, 1999). This can be accomplished if the teacher is enthusiastic not only about the content but learning as well. Student motivation can be increased by maintaining high standards for behavior and academic performance, providing appropriate challenges, encouraging students to be responsible for their own learning, and providing reinforcement (Stronge, 2007).

Teachers who are proactive about student behavior have less discipline problems. Effective classroom management includes establishing routines and procedures that will limit disruption. These should be rehearsed in the context in which they will be used. A classroom environment that is engaging increases motivation (Stronge, 2007). This does not necessarily mean that the learning is fun. It does mean that students are moving to new affective, cognitive and physical planes that will result in a sense of accomplishment (NBPTS, 2002). Because classrooms are dynamic, teachers must be flexible and adaptable – even if it means modifying the well-written lesson plans to capitalize on a teachable moment (Stronge, 2007).

While balancing all the classroom activities, teachers must adjust for differences of the individual students. Teachers must still be equitable to students, keeping in mind that this does not mean that all students will be treated alike (NBPTS, 2002). Classroom activities should consider differences in students' prior knowledge, learning styles, interests, and social needs (Benjamin, 2002 and Zubrowski, 2007). Teachers should avoid favoritism. Misbehavior should be dealt with individually (rather than whole group) while emphasizing what students should be doing. Rapport and credibility are generated by emphasizing, modeling and practicing respect (Stronge, 2007). Student learning requires not only cognitive development but also self-esteem, motivation, character, and civic virtues (NBPTS, 2002). This is accomplished when a teacher cares for the students and the students are aware of this care because of the teacher's mutual respect, nurturing and listening skills. Teachers can also motivate students by encouraging them to be responsible for their own learning and providing reinforcements (Stronge, 2007).

Classroom Discourse

Classroom discourse, or communication, occurs on multiple levels within multiple contexts. Teachers need to be aware of cultural and gender differences. The rules of classroom interactions and peer pressure will effect the communication as well. In science classes, communication should include hands-on activities, particularly those that involve problem-solving processes. These should be used to teach the concept, not as a separate activity. This shifts the role of the teacher to a facilitator of learning. The roles of the science teacher will vary depending upon the model that the teacher is using. The memory model requires only student recall. Advanced organizer models are used to show hierarchical relationships. The interpretation of data model requires a reorganization of information using inductive and deductive thinking skills. The inquiry training model allows the student to control variables (Morine-Dershimer and Kent, 1999). Research suggests that higher student performance is observed in classrooms that regularly incorporate inquiry based problems, hands-on activities, critical thinking skills, and daily assessment (Stronge, 2007).

Pedagogical Content Knowledge

"Effective science teachers know how to best design and guide learning experience, under particular conditions and constraints, to help diverse groups of students develop scientific knowledge and an understanding of the scientific enterprise." (Magnusson, *et al.,* 1999, pg. 95)

Knowledge of subject matter does not mean that a person is able to teach it (Bradsford et al., 2000 and NBPTS, 2002). Teachers must combine their subject matter knowledge with their understanding of how students learn; a concept called pedagogical content knowledge. As a consequence, teachers understand how topics and problems are organized, represented and adapted to the diversity of the students (Shulman, 1986 and 2001). The teacher understands which topics are learned easily and which are more difficult. The outcome is a variety of alternative representations that can be used for instruction (Shulman, 1986). The resulting "instructional repertoire" combines instructional techniques and curriculum resources with the mix of students and school contexts (NBPTS, 2002). In order to teach successfully, a teacher must understand the topic to be learned and how it should be taught (Shuman, 1987). This includes an understanding of why the knowledge is important and how it relates to life (Shulman, 1986). To do this, a knowledge base must be present. The knowledge base for teaching would have several categories, starting with content knowledge and general pedagogical knowledge (Shulman, 1987).

Knowledge of the intended curriculum is also needed. Pedagogical content knowledge, a mixture of content and pedagogy unique to the content area also must be understood. A teacher must have knowledge of learners and their characteristics (Shulman, 1987). For science teachers in particular, this includes the knowledge and beliefs about their students' understanding of specific science topics (Magnusson, et al., 1999). Education contexts such as the workings of classroom, school district and communities are included in the knowledge base as are the goals and values of education. Most of these are imbedded in the five standards for National Board Certification.

Teachers acquire this knowledge base from a variety of sources. First is the scholarship in content disciplines – the information within the content area and the historical and philosophical background of the content area (Shulman, 1987). In science this would include the nature of science and its processes. The teacher must understand the organization of the content to illustrate the relationship to the students. This demonstrates to the student which information is important and which is just interesting.

Another source of knowledge base is materials and structures. These include curriculum, assessment materials, institutional rules and policies, professional organizations and government agencies. The matrix produced by the interaction of these sources provides the teacher with limits and support (Shulman 2001). The third source is formal educational scholarship. This is literature that provides an understanding of the processes of schooling, teaching, and learning. Historical readings, such as Piaget or Skinner, and current empirical research can lead to teacher behaviors that will positively impact student achievement. The fourth source is wisdom of practice. Expert teachers have learned which strategies are successful. These should be codified and shared with the teaching community. This is an area in which content-specific pedagogical strategies become important (Shulman, 1987).

Teachers use their knowledge base to make decisions involving the process, methods and strategies of education. This produces a cycle of pedagogical reasoning that includes comprehension, transformation, instruction, evaluation, and reflection. Deciding the beginning and ending point within the cycle is part of the comprehension within the cycle. Teacher comprehension also includes content and purposes. Content should be understood in many ways. Purposes include not only academic achievement but also student responsibility for understanding, skills, and values needed to become a contributing citizen in our society. The knowledge base of a teacher differs from that of a content specialist in the fact that content combines with pedagogy. The teacher must be able to adapt the content to the abilities and needs of the students. This leads to transformation (Shulman, 1987).

In transformation, ideas that are understood by the teacher must be arranged so that the students will comprehend. Several processes occur in transformation. First, the teacher must prepare the materials. This includes deciding what information to include and omit, how to structure the information, and breaking the information into chunks that students can handle. The teacher then presents the information to the students using analogies, metaphors, examples, and demonstrations. The information is organized using modes of teaching and educational models. These are chosen based on the characteristics of the students, such as prior knowledge, misconceptions, age, ability and interests (Shulman, 1987).

Instruction is the implementation of the decisions made during the transformation process. Teaching strategies come from the instructional repertoire and can include lecture, demonstrations, inquiry activities, cooperative learning and projects, just to name a few. These strategies must be used to adapt to the specific students in the classroom, not students in general. Every class has its own personality so instruction must be tailored to that class. Instruction is followed by evaluation – both formative and formal. It is important for the teacher to know the level of student understanding which is specific to the content area and its topics. This is another area where pedagogical content knowledge is important. The instruction should be evaluated as well. This leads to the last component of the cycle – reflection.

During reflection, the teacher reviews the instruction and the performance of the students. This process allows the teacher to learn from experience. If a lab works well, it will be used again. If it does not work well, it will be modified or replace by another activity. It is important that the instruction accomplishes the intended learning. Through this process the teacher will have a new level of comprehension that can be used as the cycle continues. As with many cycles, the steps do not have to be followed in the order in which they are presented (Shulman, 1987).

Inquiry Learning

"Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as understanding of how scientists study the natural world." *National Science Education Standards*, p. 23

Inquiry is a scientific process that allows a learner to use critical, logical, and creative thinking skills to raise and answer questions of personal interest by actively exploring the environment. To do so, requires generating a question or problem, deciding on a course of action for the investigation, collecting data through observations and formulating a conclusion using the evidence (Llewellyn, 2002). Inquiry also is the multifaceted process used by scientists to study natural phenomena and generate explanations based on evidence. Students using inquiry will build knowledge and understanding of scientific ideas as well as an understanding of how scientists work. The National Science Standards include inquiry as a standard because it encourages students to develop an understanding of scientific concepts and the processes used by scientists, and attain the skills and attitudes associated with science to explore the world around them (NSES, 1996).

Using inquiry encourages students to develop the ability to think by engaging them in the processes of asking questions, planning procedures, gathering and analyzing data, describing relationships between evidence and explanations, and communicating scientific arguments (NSES, 1996). Questions developed by students are scientifically oriented. Priority is given to evidence that will produce explanations for answering the questions. The explanations are evaluated in light of alternative explanations. Students will then communicate their explanations and justify them with the evidence gathered (Bradsford et al., 2000).

Inquiry activities can be structured by the teacher to lead students to a known outcome or they can be more open-ended explorations of unexplained phenomena (Bradsford et al., 2000) Inquiry is not the only teaching strategy that is successful in the science classroom. Teachers should use a variety of strategies with their students (NSES, 1996).

Professional Development

"Excellent science teachers have a very special and unique kind of knowledge that must be developed through their professional learning experiences."

(Loucks-Horsley, 1999, p. 4)

Professional development is the opportunity for a teacher to learn new skills and knowledge in an effort to produce an effective learning environment for students (Gess-Newsome, 2001). High quality professional development for science teachers must take into consideration that the teachers need a deep knowledge of science or content and pedagogy. Professional Development Standards are found in The National Science Standards (NSES, 1996). They are stated in Figure 2.5.

Figure 2.5 Professional Development Standards (NSES, 1996)

1. Standard A: Professional development for teachers of science requires learning essential science content through the perspectives and methods of inquiry.
2. Standard B: Professional development for teachers of science requires integrating knowledge of science, learning, pedagogy, and students; it also requires applying that knowledge to science teaching.
3. Standard C: Professional Development for teachers of science requires building understanding and ability for lifelong learning.
4. Standard D: Professional development programs for teachers of science must be coherent and integrated.

Professional development can be effective only if it informs an image of teaching and learning that expects high standards for all students (Garet, et al, 1999 and Loucks-Horsley, 1999). It must focus on both the content knowledge for the teacher and the pedagogy needed for that content area. It should be rigorous, relevant and research-based teacher (Bybee and Ben-Zvi, 1998 and Garet, et al, 1999). Professional development should provide learning opportunities for the teachers that are extended and in-depth. It should model the methods that should be used with the students and how those methods can be adapted for different types of students (Garet, et al, 1999). Science teachers must have the pedagogical content knowledge that ensures the ability to teach specific science concepts to students at a variety of developmental stages (Loucks-Horsley, 1999). As with students, learning for teachers should build on prior knowledge, immerse the teachers in "stimulating" processes (Garet, et al, 1999) which actively engages the teachers (Loucks-Horsley, 1999), allows for team work, (which encourages collegial relationships) and spreads the learning over time. Teachers need time to assimilate the information, try to apply the information with students, and re-gather for reflections and feedback (Garet, et al, 1999 and NSES, 1996). Experiencing the methodologies similar to those intended for the student increases the teacher's confidence in content knowledge and pedagogical skills (Gess-Newsome, 2001). One study showed that professional development for inquiry learning improved the teachers' ability to design inquiry-based activities but the implementation did not reflect this higher level of understanding. This suggests that teachers need more support during the implementation of inquiry (Wee, et al., 2007).

For science teachers, professional development should take into consideration the expertise of those outside of the classroom, such as researchers, and the practical knowledge of the teachers. It should be designed to draw upon the existing knowledge of the teachers, an analysis of the context, an awareness of critical issues that influence success and a repertoire of strategies for professional development. One of the strategies is to immerse the teachers into inquiry by allowing the teacher to become a learner. As the teacher experiences inquiry, she will be better prepared to help students become active learners. This type of professional development is more successful if the lead teacher has used inquiry activities successfully with students. It also should be a long-term experience rather than a one-time workshop (Loucks-Horsley, 1999).

Effective professional development is linked to federal, state, and/or district programs and standards. It is accountable for results as it is evaluated for its impact on teaching and learning. High quality professional development has three structural features: form or organization, duration, and emphasis of collective participation.

Form or organization includes groupings such as study groups, teacher networks, mentoring or a task-force rather than a traditional workshop. Workshops tend to be outside of the classroom at a scheduled time with a leader that has a specific expertise. These are characterized as ineffective for changing teacher knowledge or classroom strategies. "Reform" types of professional development include study groups, mentoring or coaching. These take place during regular school hours. They are more responsive to teachers' needs and are more likely to make a connection with classroom teaching (Garet, et al, 1999). Collaborative work provides teachers with a common language and fosters a sense of professionalism. It allows teachers to reflect and learn from their experiences (Loucks-Horsley, 1999).

Duration includes the total number of hours as well as the span over time. Longer duration provides in-depth discussions of content, student misconceptions, and pedagogical strategies. Teachers are allowed time to try new methodologies and obtain feedback (Garet, et al, 1999, Loucks-Horsley, 1999, and NSES, 1996). The classroom change associated with trying new strategies is a challenge for the teacher which requires support from others (Gess-Newsome, 2001).

Collective participation is determined by the emphasis of the professional development. It could be all school, a single department or grade level, or teachers from many schools. The advantage of professional development for the same school, department or grade level is that it provides an opportunity to discuss concepts, skills, and problems within the organization. If they share common curriculum materials, courses, and assessments, it provides time to do more integration, sustain change over time and provide a shared professional culture. A professional culture allows teachers to share instructional goals and methods, provides a forum for debates and increases the capacity for growth (Garet, et al, 1999).

Collaboration with parents is also an important aspect of teaching (NBPTS, 2002 and NCTAF, 1996). Although parents and teachers do not always agree, an effective teacher has skills to encourage positive collaboration with parents. Parents and other members of the community can be a valuable resource for the teacher. Teachers do not need to teach alone (NBPTS, 2002).

Reflective practices are a professional necessity because they are imperative for lifelong learning (Stronge, 2007). Teachers are lifelong learners who become more knowledgeable in the art and science of teaching. They need to balance the demands of teaching by combining the instructional goals with the available teaching time. Teachers must reflect on the input of students, colleagues and administrators as they refine their skills (NBPTS, 2002 and NCTAF, 1996). This process requires an honest, open mind and sufficient time (Stronge, 2007). Teachers should incorporate new findings from research into their skills as well (NBPTS, 2002). Teachers reflect on their practices because they want to be better teachers who will make a difference in the lives of their students. Reflection creates teachers with a greater sense of self-efficacy (Stronge, 2007).

Learning communities can be either the school community or the parents and the entire community. The school community encourages teachers to collaborate with colleagues to help in the development of school-site policy decisions such as curriculum and instruction, professional development for the staff, disciplinary issues, and student services (NBPTS, 2002 and NCTAF, 1996). Teachers should also be cognizant of learning goals set by the state and local authorities (NBPTS, 2002). Collaboration creates positive working relationships. Teachers will be less fearful of taking risks that may improve education for all students (Stronge, 2007).

Increased student learning is the largest motivator for change in classroom practices (Gess-Newsome, 2001). Professional development should provide teachers with the support needed to make changes in the standards, curriculum, and assessment that will foster student learning (Loucks-Horsley, 1999). It also should present content knowledge, pedagogical practices, collaborations, and an effort to change the classroom environment in such a way that student learning is affected in a positive manner (Gess-Newsome, 2001).

Summary

To ensure student success, there must be an effective classroom teacher. The effective teacher has an understanding of pedagogy which combines the knowledge of learning theory with the ability to plan and manage a learning environment for the students. An effective teacher also has a sound conceptual framework of the content area and the pedagogical content knowledge to choose instructional strategies that fit the context of the concepts. To become and remain effective, teachers must participate in high quality professional development. Professional development should address both content and pedagogy. Time should be provided for teachers to use and reflect upon the curricula and strategies so that they can learn from their experiences. Professional development produces effective teachers which in turn promote high student achievement.

CHAPTER 3 - Methodology

Purpose Statement

The purpose of this study was to investigate the implementation of a physics unit from *Visual Quantum Mechanics (VQM)* called *Solids & Light* and the professional development strategies conducted to enhance the implementation of this unit. More specifically, this investigation has been designed as a naturalistic inquiry case study to explore how implementation of the physics unit is affected by the professional development that the teachers received to prepare them to implement the unit. The case study also was designed to investigate students' understanding of the physics concepts presented through the unit and students' perception of the laboratory environment and how these perceptions affect students' interaction with the materials in the program.

Visual Quantum Mechanics began in 1995. It was written as an activity-based instruction approach of the learning cycle (Escalada, 1997). Students explore the electrical and spectral properties of light emitting diodes (LEDs) and incandescent lights as they relate to quantum principles. The professional development, conducted in the summer of 2007, included 3 days of preparation designed to provide the knowledge and skills teachers need to teach *Visual Quantum Mechanics*. The case study includes documents gathered during the delivery of professional development in the summer of 2007 as well as qualitative and quantitative data gathered as participating teachers implement the *Solids & Light* unit during the 2007-2008 academic year.

Research Questions

How does the professional development for *Visual Quantum Mechanics* influence teachers' implementation of the program?

a. How does the professional development affect the classroom implementation of individual activities within the program?

b. What instructional strategies are most commonly used by the teachers using the *Solids & Light* unit?

How does implementation of *Solids & Light* affect student learning?

a. How does student perception of laboratory experiences affect their interaction with *Solids & Light* materials?

b. Do students develop a conceptual understanding of the quantum mechanics in the unit?

Overview of *Visual Quantum Mechanics*

Solids & Light is unit within a larger project called *Visual Quantum Mechanics* (*VQM*) which was developed by the Kansas State Physics Education Research Group in 1995. An overview of the program is shown in Data Table 3.1. The purpose of the program is to explore quantum principles using the activity-based instructional approach of the learning cycle (Escalada, 1997). Many introductory level physics courses omit quantum mechanics concepts because they are abstract and require higher levels of mathematics. However, many modern electrical devices such as computers and cell phones rely on circuits that contain small parts that operate using the principles from quantum mechanics. Students do need to have some knowledge of these concepts to understand how the electrical devices function. *VQM* was developed to introduce quantum mechanics principles to high school level students. The LEDs were chosen because they are part of every day life, are easily obtained and have characteristics that can easily be compared to incandescent lights (Ztec, 2002).

Table 3.1 Overview of *Visual Quantum Mechanics*

Units in *VQM*	**Activities in *Solids & Light***	**Correlation to Learning Cycle**
Potential Energy Diagrams		
Waves of Matter		
Exploring the Very Small		
Luminescence: It's Cool Light		

Solids & Light		
	1. Exploring LEDs and Lamps	Exploration
	2. Exploring Light Patterns	Exploration
	3. Introducing Energy Diagrams for Atoms	Concept introduction
	4. Understanding the Spectra Emitted by Gas Lamps	Concept introduction
	5. Applying Spectra and Energy Diagrams to Learn About Stars	Concept application
	6. Using Spectra to Search of an Earth-like Planet	Concept application
	7. Using Gas Lamps to Understand LEDs	Concept introduction
	8. Applying Energy Bands to Incandescent Lamps	Concept application
	9. Creating an Energy Level for Model LEDs	Concept introduction
	10. Applying Energy Level Models to LEDs	Concept application
	11. Can Ohm's Law Explain Your Observations?	Optional: Concept application
	12. Using LEDs to measure Planck's Constant	Optional: Concept application

The instructional model used in the development of *VQM* is the Learning Cycle developed by Robert Karplus and his colleagues (Escalada, 1997). The learning cycle has three stages; exploration, concept introduction, and concept applications. Exploration allows the student to interact with the environment in a fashion that raises questions that produce a cognitive disequilibrium (Karplus, 1977). The *Solids & Light* unit begins with exploration when the students perform experiments using hands-on activities. Concept introduction begins with the definition of the concept and aides the students in applying new patterns to the experiences. This information can be supplied by the teacher, a textbook, or another type of educational material (Karplus, 1977). The students learn the new concept in the *VQM* program with the aid of the instructor and activities that include computer simulations. The concept application stage familiarizes the student with the new concept as it is used in additional situations (Karplus, 1977). There are several activities in which the students use the new concept in real-life situations (Ztec, 2002).

The student objectives specific for *Solids & Light* from the teacher materials for the program include the ability to:

a. "compare the light emitting properties of LEDs and gas lamps with those of incandescent lamps,
b. observe, describe, and identify the characteristic spectra emitted by gas lamps, incandescent lamps, and LEDs,
c. observe the color changes with energy input of an incandescent lamp,
d. describe and differentiate between the color and intensity of light within the context of photons,
e. understand that an atom's energy can be represented by an energy level diagram,
f. learn, through observation, that an electron in an atom can only have certain allowed energies,
g. apply energy diagrams to explain the spectra emitted by gases,
h. apply conservation of energy and energy diagrams to build an energy band and gap model,
i. apply the model of energy bands to explain the properties and operation of the LED and incandescent lamps, and
j. apply the energy level to explain the electrical directionality of LEDs" (Ztec, 2002).

Research Design

This project was a naturalistic inquiry case study of a the *Visual Quantum Mechanics* curriculum, the professional development conducted to enhance the implementation of this curriculum, and the impact the curriculum and professional development have on teaching and learning. The case study provides a summative evaluation to determine both the merit and the effectiveness of the *Solids & Light* program. The evaluation provides evidence that may be used to enhance future physics curriculum projects and professional development efforts.

The investigative process occurred in the classroom. This natural setting provides the context for the study. Instead of controlling as many factors as possible, naturalistic inquiry allowed the researcher to monitor everything that could possibly influence the outcome (Lincoln and Guba, 1985). The researcher was an instrument for data collection. As such, the researcher was responsive to the cues in the environment and was adaptable to assessing many factors simultaneously. Data were processed immediately and feedback occurred quickly. Atypical data were investigated in more detail when it was deemed important to the results (Lincoln and Guba, 1985). The type of data emphasized by naturalistic inquiry is qualitative. This occurs because the human-as-instrument is more easily achieved with qualitative data (Lincoln and Guba, 1985). This study used both qualitative and quantitative data. Triangulation of both types of data provides greater credibility. Combining data from different methods allows data to emerge to show consistencies (Fraser and Tobin, 1991).

The Setting

The physics department at KSU in Manhattan, Kansas is participating in a national program called QuarkNet. QuarkNet is a project funded by the National Science Foundation (NSF), the United States Department of Energy (DOE), ATLAS, CMS and Fermilab. The goal of the project is to help teachers reach a deeper understanding of physics content with an emphasis on inquiry learning and modern (particle) physics concepts. There are approximately 50 universities and labs participating in the QuarkNet program. The KSU group focused its recruitment on rural schools in Kansas. They started with four lead teachers during the summer of 2003 and added an additional twenty teachers the following summer. Teachers came to participate in QuarkNet from across the state of Kansas. The number of participating teachers has varied over the last several years. To encourage more involvement, a search for new teachers was conducted during the spring of 2007. Part of the professional development provided for the new group included information about the *Visual Quantum Mechanics* program.

The schools for this study were determined as the teachers from the summer institute volunteered to participate. Because of the range of schools involved with QuarkNet, the study could have included schools from size 1A to 6A. Physics classes were as small as 2 students and as large as 25 students. The class schedule could have been a traditional eight hour day or a block schedule. Computers may have been in the physics classroom or available only in a computer lab. All of these factors influenced the way that the *Solids & Light* unit was implemented in the classroom.

Participants

The classrooms in the observational study were selected on a volunteer bases from the group of teachers who participated in a week of professional development on modern physics that was sponsored by the Kansas State University QuarkNet group. The participating teachers all teach physics and/or physical science. Most are from public schools in Kansas and teach at the middle and/or high school level. Because KSU focused on recruiting rural teachers, many of the teachers also teach other content areas such as chemistry, biology and mathematics. There were approximately 20 teachers in the workshop. Two of them are retired. One of the retired teachers is currently teaching part-time. Seven of the teachers have been participating in QuarkNet for three years and the others were new to the program in 2007.

Selection of Participants

Teachers who participated in the summer workshop were asked to volunteer to be participants in the observational study. Approximately four teachers showed some interest in participating during the week of the workshop. The QuarkNet mentor asked the teachers to be lead teachers who would travel and train additional teachers in the use of *Solids & Light*. Six teachers agreed to be lead teachers and were provided additional support in the use of *Solids & Light*. The researcher talked to these teachers at their follow-up session and all teachers from the workshop received a letter by email to encourage them to volunteer for this project. Four teachers, who are also lead teachers, volunteered to participate in the observational study.

Teacher A teaches at a suburban school with a population of 796 students of which 91% are white and 22% are eligible for free or reduced lunch. There are 90 certified staff members which includes six science teachers. Teacher A is currently working on his master's degree in physical science education and is certified to teach biology, chemistry, physics, earth/space science and general science. He has 12 years of teaching experience and has taught anatomy, electronics, and chemistry in addition to physics. He was teaching honors physics and chemistry at the time of the study.

Teacher B teaches in a small town school with a population of 323 students of which 65% are white and 63% are eligible for free or reduced lunch. There are 25 certified staff members which includes 3 science teachers. Teacher B has a Master's of Science in science education and is certified to teach biology, chemistry, physics, and general science. She has been teaching for 14 years which includes 7 years of physics. She has also taught biology, physical science, anatomy, earth science, Principles of Technology, and Applied Biology and Chemistry. She was teaching physics and chemistry at the time of the study.

Teacher C teaches in a small town school with a population of 94 students of which 100% are white and 26% are eligible for free or reduced lunch. There are 12 certified staff members which includes two science teachers. Teacher C is currently working on her master's degree in physical science teaching and is certified to teach 7-12 mathematics, general science, physical science, and physics. She has nine years of teaching experience at the high school level as well as 14 years of teaching college algebra at the junior college level. Teacher C was teaching general physical science, physics, trigonometry and calculus at the time of the study.

Teacher D teaches in a rural school with a population of 277 students of which 97% are white and 10% are eligible for free or reduced lunch. There are 20 certified staff members which includes three science teachers. Teacher D has a Ph.D. in botany and is certified to teach biology, chemistry and physics. He has 12 years of experience teaching botany, ecology, genetics, zoology, plant taxonomy, microbiology, general biology, middle school science, applied biology and chemistry, anatomy, advanced placement (AP) chemistry, AP physics, chemistry, physics and foundations of physics. He was teaching physics and ninth grade foundations of physics at the time of the study.

Professional Development

The professional development occurred as a Summer Institute during July 23-27, 2007. Participating teachers met from 9 A.M. to 4 P.M. each of these five days for a total of 30 hours.

Mornings were spent in lectures that discussed high-energy physics concepts. Teachers toured the Nuclear Reactor at KSU on Monday, the first day of the institute. They toured the Laser Lab on Wednesday afternoon. Friday, the last day of the institute, was spent at the Cosmosphere in Hutchinson, KS where the major topic was rockets. There were four 90-minute sessions devoted to the *Solids & Light* unit of the *Visual Quantum Mechanics* program. The *Solids & Light* unit consists of a series of twelve activities that involve hands-on experiences and computer simulations. The first four activities from the unit were practiced during the institute, the next three activities from the unit were discussed during the institute and the final five activities from the unit were given to participants, but not discussed.

On Tuesday morning, the teachers began Activity 1 – "Exploring LEDs and Lamps." In this activity the students use a circuit board equipped with a potentiometer to compare an incandescent bulb, LEDs of several colors and Christmas tree bulbs for the light that they produce, their threshold voltage, and their maximum voltage. The participants completed the activity as students would. There was a group discussion to compare results. Activity 2 – "Exploring Light Patterns" was completed Tuesday afternoon. In this activity, students observe gas lamps, an incandescent lamp and the LEDs through a spectroscope. Discussions within the activity allow comparisons of the characteristics of each light source. However, the discussion in the teacher workshop did not follow the questions from the lab as closely as the Activity 1 discussion earlier that day. Teachers were given Activity 3 – "Introducing Energy Diagrams for Atoms" but they did not do this activity. This activity uses energy diagrams to explain the energy changes that occur when an electron moves from one energy level to another.

During Wednesday afternoon, the teachers were accommodated with individual use of computers to complete Activity 4 – "Understanding the Spectra Emitted by Gas Lamps." This is a computer simulation called "Spectroscopy Lab Suite" which allows students to observe the energy diagrams and light spectra for gas lamps simultaneously. Discussion of Activity 4 occurred on Thursday afternoon.

The handouts for activity 5 – "Applying Spectra and Energy Diagrams to Learn About Stars", Activity 6 – "Using Spectra to Search for an Earth-like Planet", and Activity 7 – "Using Gas Lamps to Understand LEDs" were given to the teachers and discussed briefly but teachers did not have time to do these activities. In Activity 5, students use the "Spectroscopy Lab Suite" to compare emission spectra and absorption spectra and describe how the absorption spectra are used to learn about stars. In Activity 6, students compare the spectra of gases found in Earth's atmosphere to those of unknown planets to find an Earth-like planet. Activities 5 and 6 could be considered optional activities because they are application activities that are not assessed in the program. Activity 7 takes the student back to the "Spectroscopy Lab Suite" to investigate the spectra of LEDs.

The handouts for activities 8, 9, 10, 11, and 12 were distributed but no discussion of them occurred. Activity 8 – "Applying Energy Bands to Incandescent Lamps," allows the student to use the Spectroscopy Lab Suite to apply the concept of energy bands that was learned in Activity 7, to incandescent lamps. Activity 9 – "Creating an Energy Level for Model LEDs", and Activity 10 – "Applying Energy Level Models to LEDs," use part of the computer program called "LED Constructor" to illustrate how electron donors and acceptors function in an LED and build a model to explain the physical characteristics of LEDs and incandescent lamps. Activity 11 is "Can Ohm's Law Explain Your Observations?" This activity takes the students back to the voltage data from Activity 1 to construct a voltage current graph to see if the lamps obey Ohm's Law. Activity 12 – "Using LEDs to Measure Planck's Constant" is an optional activity which is not part of the tested objectives. In this activity, students use the data from Activities 1 and 2 to calculate Planck's constant.

Date Collection

Data were collected from all the teachers who participated in the summer institute using a survey. Teachers who volunteered to implement the program in their classrooms completed two questionnaires and allowed their classes to be videotaped. A personal classroom observation was also scheduled. There are several sources of information to determine how the July training affected the implementation of the unit in the classroom. Data also were collected from students who participate in the *Solids & Light* activities. They completed a laboratory survey, a questionnaire and an assessment of conceptual understanding.

Data Collection Related to Professional Development

Five sources of data provided information related to professional development. There are results from; (1) a QuarkNet Summer Institute Evaluation Form; (2) *Visual Quantum Mechanics* journal entries completed during the summer institute; and (3) the responses from an e-mail survey completed after participating teachers have implemented the *Solids & Light* unit. In addition; (4) field notes prepared by the researcher and finally; (5) the documents or handouts given to the participants and the teaching materials provided by Ztec.

1. *QuarkNet Summer Institute Evaluation Form* - Teachers completed a QuarkNet Evaluation Form (Appendix B) at the end of the institute. The questions addressed not only the *VQM* but other QuarkNet activities from the week-long institute. This data determined the effectiveness of the professional development.

2. Visual Quantum Mechanics Journal Entries - The teachers were asked by the professional development facilitators to complete a journal entry for each day of the workshop. Teachers were instructed to write about the successes and difficulties experienced in the activities. The journal entries from the summer institute described the reflections of the teachers on the professional development provided during the summer institute.

3. Visual Quantum Mechanics Email Survey - All teachers who attended the summer institute received an email survey at the end of the 2007-2008 school year (Appendix B). The data from the analysis indicated how the professional development influenced the decision to use the *Solids & Light* unit and how the materials were actually used. The email survey described the factors that influenced those teachers who chose not to implement *Solids & Light* in their classrooms.

4. Field Notes – A summary of the researcher's notes, reflections and impressions helped to establish themes within the professional development data and how it related to the teaching strategies used with implementing the unit. The researcher also attended the professional development provided by two of the new lead teachers. Notes and reflections from these observations are part of the professional development data because this experience may have affected the way the lead teacher uses the program with students.

5. Documents – The summer institute teachers were provided with a handout for each of the activities in the *Solids & Light* unit. In addition, there are teaching resources such as objectives and assessment questions provided with the purchase of the *Visual Quantum Mechanics* program from Ztec.

Data Collection Related to Instructional Strategies

Five sources of data provided information on the instructional strategies used by participating teachers as they implement the *Solids & Light* unit; (1) a participant information form; (2) two instructor questionnaires completed by participating teachers; (3) interviews with participating teachers; (4) classroom observations of participating teachers; and (5) researcher field notes.

1. Participant Information Form – This form (Appendix B) provided demographic information about those teachers who volunteered to participate in the observational study while they implemented *Solids & Light*. This data show the extent that the participants have used computers and inquiry learning activities prior to beginning the *Solids & Light* unit. This information was compared to the students' perception of the lab environment as well.

2. Instructor Questionnaires - Teachers who volunteered to participate in the observational study were asked to complete the Teacher Questionnaires A and B (Escalada, 1997) as they completed activities with their students. Questionnaire A (Appendix B) discusses Activities 1-6 and B (Appendix B) discusses Activities 7-12.

3. Interviews - There was an interview with each teacher after the first classroom observation and an exit interview when the unit was completed. The questions for these interviews are found on the observation protocol (Appendix B). Data from the interview questions used after the first classroom observation investigated the teacher's reflection of student progress. The interview at the end of the unit determined the relationship between the implementation of the program and the professional development and the teacher's other previous experiences.

4. Classroom Observation Protocol - The Classroom Observation Protocol found in Appendix B (Young, 1995) has been used to collect data on the instructional strategies used by the instructors. Most class sessions for the unit have been videotaped for this observation. The classroom observation protocol has been modified to include a frequency chart to plot activities of the students at specific times. The specific inquiry-type behaviors were devised from a list of essential features of classroom inquiry developed by the National Research Council in 2000 (Cianciolo, Flory, and Atwell, 2006). In addition, some questions were modified to specifically address *Solids & Light*. The researcher's personal classroom visit was made as the participating teachers implemented one of the first four activities in the *Solids & Light* unit. Observational data provided a wide variety of information regarding the physical environment, teaching strategies, student activities, materials used and assessment strategies.

5. Field Notes – A summary of the interviews and observations that include the researcher's reflections and impressions helped to establish themes that emerged from data regarding teaching strategies and shows how it is related to the professional development. The summary also shows how the teaching strategies influence student learning.

Data Collection Related to Student Learning

Five sources of data will provide evidence of student learning; (1) the Science Laboratory Environment Inventory; (2) interviews with students; (3) pre- and post-test comparisons; (4) student questionnaire; and (5) researcher field notes.

1. Science Laboratory Environment Inventory - To determine the students' perception of the laboratory, the Science Laboratory Environment Inventory (SLEI) in Appendix B was given to the students before beginning *Solids & Light*. The questions on this survey determine the classroom climate based on five broad categories; student cohesiveness, open-endedness, integration, rule clarity, and material environment. The SLEI was field-tested in six countries and cross-validated with data taken in Australia (Fraser, Giddings, McRobbie, 1995). There are two forms of the SLEI; the class form which asks the questions in relationship to the class as a whole and the personal form which asks the questions in an individual form. Both forms have been developed to ascertain the students' actual lab experiences (actual form) and their preferred lab environment (preferred form). Students completed the class actual form (Fraser, Giddings, and McRobbie, 1995). The survey was modified to include the 21 questions that address open-endedness, integration, and material environment. This determined the students' perception of the laboratory environment prior to beginning the *Solids & Light* unit.

2. *Interviews* - Selected students were interviewed on the day of the personal classroom observation (Appendix B). Questions for the interview explored the students' perceptions of the activities and their reflections on what they learned through the activities.

3. Pre-test/Post-test - Students completed a pre-test and post-test (Appendix B) to determine their learning of the quantum physics content within the *Solids & Light* unit (Escalada, 2007).

4. Student Questionnaires - Students also completed a Student Questionnaire (Escalada, 1997) to assess their success in using the materials from the unit and what they thought they had learned in the process of completing the *Solids & Light* unit. Questionnaire A (Appendix B) discusses Activities 1-6.

5. Field Notes – A summary of the interview and the researcher's reflections and impressions was used to help establish themes in the students' perception of their learning and how the teaching strategies and unit materials influence them.

Date Analysis

Analysis of the qualitative data is inductive in nature. The data have been used to determine the categories and relationships of the observations. Content analysis divides the data into units of meaning that can be quantified (Lincoln and Guba, 1985). This type of analysis has been used on the Likert scales and tallies that are in the data. There is a typological analysis included in the Classroom Observation Protocol. Thematic analysis has been used for the interview questions and any open-ended questions. This analysis used a coding process. Coding allows the text in the data to be organized into broad themes based on the data bank itself. This allows repetitions and relationships to be determined (Creswell, 2002 and Krathwohl, 1998). Relationships can be further described by using constant comparisons of the data between categories (Lincoln and Guba, 1985). A thematic coding process also allowed a layering of themes to show their interconnectedness (Creswell, 2002) as the professional development influenced the teaching strategies which in turn influenced student learning. The pre-test and post-test have been treated as quantitative data. Analysis by the t-test and effect size determined the statistical significance for the difference between the two means of the pre-test and post-test. A comparison of the effect size and t-test between schools also proved to be informative.

Analysis of Professional Development Data

1. *QuarkNet Summer Institute Evaluation Form* – One of the questions on the evaluation form is designed as a Likert scale. Content analysis to determine frequencies has been used with these data. The open-ended questions are qualitative in nature and are thus appropriate for thematic analysis.

2. VQM Journal Entries – The journal entries also yielded qualitative data to be treated by thematic analysis.

3. VQM Email Survey – Those questions that are qualitative in nature were analyzed using content analysis. Several of the questions require only yes or no answers, while others are items to be ranked. Thus, frequencies were calculated for these questions.

4. Field Notes – The notes and reflections of the researcher are qualitative data so thematic analysis has been used.

5. Documents – Content analysis has been used for these qualitative data because the information influences the use of the *Solids & Light* unit.

Analysis of Instructional Strategy Data

1. Participant Information Form - The frequencies for the demographic data have been calculated. Content analysis has been used to process the qualitative data.

2. Instructor Questionnaires –Thematic analysis has been used on the open-ended questions. Content Analysis has been used for the Likert scaled questions.

3. Interviews – Thematic analysis has been used because this data consists of open-ended questions.

4. *Classroom Observation Protocol* - There is a tally sheet in question #10 that provides data at time intervals to show the frequencies of teaching and learning activities.

Content analysis has been used for this data. Questions #12 and 13, the typology pages and the reflections and interpretation were completed by the researcher immediately following the observation. The typology is the observer's interpretation of the teacher's instructional strategies on a continuum without value judgments (Young, 1995). The specifics of the typology are explained within the protocol form.

5. Field Notes – The notes and reflections of the researcher are qualitative data so thematic analysis has been used.

Analysis of Student Learning Data

1. Science Laboratory Environment Inventory – The modified survey contains 21 questions in a Likert format. The average mean score as well as a percentage for each of the three categories was tabulated for student perceptions prior to *Solids & Light*.

2. Interviews - Thematic analysis of answers to the interview questions has been used because the questions are open-ended.

3. *Pre-test/Post-test* – Questions on the pre-test and post-test (Appendix B) assess the unit objectives. Effect size and t-scores have been calculated to determine the level of student learning.

4. Student Questionnaires – Thematic analysis was used on responses to the open-ended questions. Frequencies were calculated for data from the Likert scaled questions.

5. Field Notes – The notes and reflections of the researcher are qualitative data so thematic analysis was used. A visual summary of the data collection is presented in Data Table 3.2.

Table 3.2 Overview of Data Analysis

Data Collection Approach	**Analysis Plan**	**Responders**	**Type of Data Collected**
QuarkNet Summer Institute evaluation form	Content analysis on Likert scale Thematic analysis	VQM summer participants	Affect of PDC
VQM journal entries	Thematic analysis	VQM summer	Affect of PDC

		participants	
VQM email survey	Content analysis	VQM summer participants	Affect of PDC
Field Notes	Thematic analysis	Researcher	Affect of PDC
Documents	Content analysis	Researcher	Affect of PDC
Implementer Information Form	Content analysis to calculate frequencies	Teachers	Demographics and instructional strategies
Instructor Questionnaires	Content analysis on Likert scale and Thematic analysis	Teachers	Affect of PDC on implementation and instructional strategies
Informal Interviews	Thematic analysis	Teachers	Implementation, instructional strategies
Classroom Observation Protocol	Content analysis and typology	Observation of Students/Teachers	Instructional Strategies and student learning
Field Notes	Thematic analysis	Researcher	Instructional strategies
Science Environment Laboratory Inventory	Content analysis to calculate frequencies	Students	Perception of Laboratory environment
Informal Interviews	Thematic analysis	Students	Use of materials and student learning
Assessment: Pre-test and Post-test	Analyze scores and responses (T-scores and Effect size)	Students	Student learning
Student Questionnaires	Content analysis on Likert scale and Thematic analysis	Students	Student learning and classroom environment
Field Notes	Thematic analysis	Researcher	Use of materials and student learning

Role of the Researcher

I am a high school science teacher with 30 years of experience in the classroom of a rural school district. The content areas I teach include physics, chemistry and biology. I believe teaching is an adventure. It can never be boring because no two days are alike. In fact, no two classes are alike, and no two students are alike – not even the identical twins that I taught. While the students in my classes have different learning styles and learn at different paces, all students can and do learn. I could not be a teacher without believing this. Believing this means that I can come to school on a daily basis, prepared to teach three content areas to the students in my six blocks. I can maintain high expectations for myself and for my students. To be successful, my students must know that I expect them to learn to the best of their abilities.

Enthusiasm is an important component of my teaching. I must be enthusiastic about the content that I teach. Students must observe that it is important to me so that they can see that it is also relevant to them. While I am the facilitator of learning, the students are ultimately responsible for their own learning. It is my responsibility to help them want to learn and give them the opportunity to learn not only the content area of the course but process skills, such as problem-solving, as well. The result is a classroom in which the students know the expectations for each activity. Students know that they will be assessed regularly regarding content areas.

Students like a certain amount of routine in their lives. We are on a block schedule, so I follow a similar schedule each day and for each unit. My teaching style is a combination of traditional and contemporary ideas. We begin with an activity I call "sponge questions." These questions may probe for prior knowledge, review previous content, or explore the results of the last laboratory experience. I introduce the next concept verbally and visually; in other words, I give a short lecture. The verbal and visual learners need this in order to become more comfortable with the content. This is followed by a small group activity. While some of the activities are discussions, most are hands-on labs, many of which will contain inquiry learning. The kinesthetic learners like these types of activities. Finally, I use the learning cycle a couple of times a year because I understand that it matches the way that people learn. I also know from personal experience how hard it is to change what one has been doing for twenty years. Each year, I try to change one or two activities to match the learning cycle. Last year, I added the *Solids & Light* unit to my physics curriculum.

I think that it is important to do interdisciplinary activities as well. All my classes have at least one writing project per semester. Some are more creative, such as the famous scientist poster that includes a job resume and a personalized license plate. I try to make some projects relevant to the students' lives, such as the *caveman to chemist* project that includes the history, preparation, and comparison study of something we use everyday or a paper explaining microbial diseases and their treatments. I also have developed several learning centers which include inquiry activities. These centers allow differentiated instruction, not only for different learning styles but for different ability levels as well. One of my learning centers is focused around the concept of fundamental particles, a topic chosen when I became involved in the QuarkNet program.

I became a lead teacher for the QuarkNet program at Kansas State University in the summer of 2003. At that time, I was instructed in the use of the *Visual Quantum Mechanics* program. I used activities 1-4 of *Solids & Light* in my chemistry classroom prior to the 2007 KSU summer institute in which I was a participant observer. As such, I needed to maintain objectivity in the study. This meant that I needed to be consistent in the way I viewed the evidence. Prolonged engagement will provide consistent evidence and familiarity with the program will provide stability in the observations of the program (Krathwohl, 1998). Other efforts to enhance my credibility as a participant observer are described under quality considerations.

Quality Consideration

Rights of Human Subjects

The Kansas State University IRB process has been followed. The process for approval required by each of the individual school districts was followed as well. Teacher participants were asked to complete an observation consent form and I took care to obtain parental approval for all student participants. The names of the schools, teachers, and students are kept anonymous.

In addition, I have maintained an audit trail to allow others to check my reasoning and process and to provide greater methodological rigor (Krathwohl, 1998). Furthermore, I have employed an important technique of member checks that establishes credibility (Lincoln and Guba, 1985). For this process, a transcribed copy of the interview was given to each participant to be checked for accuracy. The summaries and reflections of the interviews have gone through a member check process in which they were given to a gatekeeper who is a faculty member at the University of St. Mary to be sure that my portrayals are accurate (Krathwohl, 1998). To add further credibility, peer debriefing has been performed by a faculty member at Kansas State University.

Credibility

In a naturalist inquiry, internal validity is represented by credibility. For the inquiry to be credible, the research must be designed so that it is probable that the data is reliable (Lincoln and Guba, 1985) Activities that increase credibility include prolonged engagement, persistent observation and triangulation of data. Prolonged engagement is ensured by an adequate time schedule to achieve the purpose of the study (Lincoln and Guba, 1985). In this study, multiple activities from the *Solids & Light* unit were observed in each classroom. Persistent observation has the ability to identify the characteristics and elements that pertain to the issue at hand. In this study, the classroom activities were videotaped in order to allow the researcher to review the data multiple times as new trends appeared. Triangulation of data requires the use of several data sources to produce multiple sets of data (Lincoln and Guba, 1985). These data sets reveal consistencies in the data (Fraser and Tobin, 1991). In this study, multiple sets of data were acquired from the teachers in the summer institute through their responses to the questions about professional development and its affect on implementation. There are multiple sets of data for teachers who volunteered to implement the program through their responses to the questions about implementation. Students also produced multiple sets of data to provide evidence of student learning.

Transferability

Generalization of this study is not possible. However, readers can determine the transferability of these findings to their own environment. Those from similar school districts may be able to use this study to determine the type of professional development that would help their teachers implement the *Solids & Light* unit to provide improved student learning of physics concepts.

Summary

This chapter described the research issues of professional development, instructional strategies and student learning. The methodology for this study was described to include such topics as participant selection, data collection and analysis, and quality considerations. Chapter four will present the data resulting from the study. Chapter five will discuss the conclusions and recommendations that become apparent from the data.

CHAPTER 4 - Analysis of Data and Presentations of Findings

Introduction

The purpose of this study was to investigate the implementation of a physics unit from *Visual Quantum Mechanics* called *Solids & Light* and the professional development strategies conducted to enhance the implementation of this unit. In addition, the study also was designed to investigate students' conceptual understanding of the physics concepts presented through the unit. The following questions guided all data collection and analysis decisions:

How does the professional development for *Visual Quantum Mechanics* influence teachers' implementation of the program?

a. How does the professional development affect the classroom implementation of individual activities within the program?
b. What instructional strategies are most commonly used by the teachers using the *Solids & Light* unit?

How does implementation of *Solids & Light* affect student learning?

a. How does student perception of laboratory experiences affect their interaction with *Solids & Light* materials?
b. Do students develop a conceptual understanding of the quantum mechanics in the unit?

Chapter 4 provides the results of this study. A discussion of the final conclusions and recommendations will be included in chapter 5.

Results

As described in Chapter 3, the researcher used multiple sources to collect data to answer the questions about the professional development, teaching strategies and student learning for the *Visual Quantum Mechanics* program unit called *Solids & Light*. Data regarding professional development were collected from all the teachers who participated in the summer institute. Participants completed an evaluation form and were asked to write journal reflections about each of the *VQM* sessions. All teachers also were sent an email survey at the end of the school year to determine how they used the *VQM* program with their students. Finally, the researcher has recorded field notes and provided supporting documents.

Data regarding instructional strategies were provided by the teachers who volunteered to implement the program in their classrooms. They completed two questionnaires, granted two interviews, allowed their classes to be videotaped, and allowed a personal classroom observation by the researcher.

In addition, data regarding student learning were collected from students who participated in the *Solids & Light* activities. They completed a laboratory survey, one questionnaire and an assessment of conceptual understanding. The results from the professional development, instructional strategies, and student learning will be presented separately.

Professional Development

Five sources of data were collected from the teachers who participated in the summer institute to provide information related to professional development; (1) QuarkNet Summer Institute Evaluation Form which was completed by teachers at the end of the summer institute; (2) *Visual Quantum Mechanics* Journal Entries which teachers were requested to complete during the summer institute; (3) *Visual Quantum Mechanics* Email Survey which was completed after participating teachers implemented the *Solids & Light* unit; (4) field notes which were prepared by the researcher, and include all the records of the professional development activities and the participant observer notes and reflections; and (5) documents which include those handouts given to the participants as they learned about the *Solids and Light* unit and the teaching materials provided by Ztec with the purchase of the program.

1. QuarkNet Summer Institute Evaluation Form - Sixteen of the 20 participating teachers completed a QuarkNet Evaluation Form (Appendix B) at the end of the institute. The questions addressed not only the *VQM* but other QuarkNet activities from the week-long institute. Overall, the institute received very positive responses. There were 4 responses in the "Not applicable" column and only 3 in the "Disagree" column. Data for the results of the Likert scale are found in Data Table 4.1.

Table 4.1 Results of Likert Scale on QuarkNet Evaluation Form

	Strongly agree	**agree**	**disagree**	**Strongly disagree**	**N/A**
	1	2	3	4	
a. The program staff responded effectively to my questions	11 = 69%	5 = 31%			
b. The materials that were provided will be of use in the classroom	5 = 31%	10 = 63%			1 = 6%
c. I feel confident to implement VQM in my classroom	5 = 31%	9 = 56%	1 = 6% 1 = 6%		
d. I understand the roles discipline other than mine play in creating VQM	4 = 25%	11 = 69%			1 = 6%
e. QuarkNet expectations for me were made clear	7 = 44%	8 = 50%	1 = 6%		
f. School year expectations for my group were made clear	4 = 25%	10 = 63%			2 = 13%
g. I had significant opportunity to interact with teachers in my neighborhood group	10 = 63%	6 = 38%			
i. Opportunity to interact with teacher in my discipline was helpful	12 = 75%	4 = 25%			

The highest numbers of teachers (75%) strongly agreed that the opportunity to interact with other physics teachers was very helpful. A large number of teachers (69%) strongly agreed that the program staff responded effectively to questions. When the participants were asked if they were confident regarding implement *VQM* in their classroom, 31% strongly agreed and 56% agreed. In response to the question addressing how other disciplines influence *VQM*, 25% strongly agreed and 69% agreed.

The open-ended questions on the evaluation form addressed the preferred topics for a follow-up session, the learning in the institute, and general comments. These comments were analyzed by content. The answers to the question about follow-up topics were divided into four categories; "detectors physics," "particle physics," "physics knowledge base," and "teaching strategies". The responses are found in Data Table 4.2. Each box represents a cluster of teacher comments.

Table 4.2 Summer Institute Evaluation - Follow-up Topics

Detectors Physics	Particle Physics	Physics – Knowledge Base	Teaching Strategies
How to use the CRD and labs for the detector	Improvements in understanding muons and cosmic rays	Potential energy and particle & wave nature of light	Collaboration and help from every member
Applications of the muon detector	Dark holes, dark matter, dark energy	Review the materials from the 3 wk class as a continuing development of knowledge base	Specific examples of curriculum maps that include Quarknet activities
		I would like to better understand gravity waves.	I would like help to incorporate high energy physics into my existing curriculum
		More content, not just unique ways to teach the same stuff we are already teaching	How to simplify the material to use in 8th grade

The requested topics in the "detector physics" category included learning how to use the cosmic ray detector, labs and/or classroom activities for the detector, and applications for the muon detector and cosmic ray detector. In the "particle physics" category there were requests for information about muons and cosmic rays. In the "physics knowledge base" category, information was requested about potential energy, the wave and particle nature of light, and gravity waves. In addition, one teacher asked that all information from this and the previous workshops be reviewed as a way to improve the knowledge base. One teacher also asked for more content because "I would prefer not having workshops on just unique ways to teach the same stuff we're already teaching." The "teaching strategies" category includes requests for more collaboration and ideas to help incorporate quantum physics into the current curriculum.

Teachers were asked for the three most important things learned from the institute. These comments were organized within five categories: "modern physics," "physics knowledge," "*Visual Quantum Mechanic,"*, "teaching strategies," and "KSU information." The data for these comments is found in Data Table 4.3. Each box represents a cluster of teacher comments.

Table 4.3 Summer Institute Evaluation - Most Important Things Learned

Content Topics	Participant statements
Modern Physics	Better understanding of high energy/quantum physics - Antimatter - Feynman's diagrams - Dark energy/matter - Cosmic rays - Activities at Fermilab and CERN
	Better understanding of relativity - Time dilation - Length contraction
	Compression & expansion of particle pulses
	Composition of the universe
	Matter is not necessarily conserved like energy is
	Knowledge of high energy physics
VQM	*VQM* unit specifics - Resources available such as curriculum - How to use software
	Hands-on with *VQM*
	Attained from using *VQM*: - Better understanding of the spectrum - Difference between incandescent & LED
Physics Knowledge	What we do not know in physics especially about the universe
	Uses of laser
	Loved learning more historical aspects of who did what , when, how
Teaching Strategies	Integrate concepts in modern physics into my physical science lessons
	Activities and approaches that other physics teachers use
	Overlap between chemistry and physics
KSU Information	Contacts at KSU
	Demonstration of cosmic detector

The topics learned in "modern physics" included anti-matter, dark matter, Feynman diagrams, particle pulses, the theory of relativity, clear misconceptions in high energy physics, the research being done at Fermilab and CERN, time dilation, an introduction to quantum electrodynamics, cosmic rays and high energy physics. Within those comments, 50% of the teachers described learning about dark matter and anti-matter. The "VQM" category was mentioned by 50% of the teachers. In the comments, they addressed the resources that are available, the hands-on nature of the program, how to use the program in the classroom, and the differences between incandescent lamps and LEDs.

In the “physics knowledge” category, teachers described the learning of historical aspects of physics, the use of lasers, and the fact that we really only know a limited amount of information about the universe. Our limited knowledge was mentioned by 38% of the teachers. In the “teaching strategies” category, teachers commented on learning how to integrate modern physics concepts into physical science lessons, use activities and approaches that other physics teachers use, how to integrate the subject matter chemistry, physics, and light, and the extent that chemistry and physics topics can overlap when discussing atomic/nuclear information. The comments in the “KSU information” category included learning contacts at KSU and the cosmic ray detectors that are available at KSU.

The general comments were separated into two groups; positive comments about the institute and negative comments about the institute and are displayed in Data Table 4.4. Each box represents the comments made by a single teacher.

Table 4.4 Summer Institute Evaluation - General Comments

Positive Comments	**Negative comments**
KSU staff is accommodating Lecture were well received Nice facilities. Good demonstration of the use of the cosmic ray detector	The tour in the laser lab “lost” me
I have learned a great deal from the QuarkNet I have developed better teaching skills. The KSU faculty has been wonderful. QuarkNet provides us the opportunity to network on a state wide level.	Give us a list of participants and everyone wear Nametags all week
Good opportunity to visit with other science teachers. I learned a lot from Dr. Weaver & Bolton’s discussions.	Unsure of the expectations of me within the group. Some of the ideas and opportunities seem to be too good to be true.
I learned I have a limited understanding but I am learning Physics.	
Thank you so much for continuing this. I wanted to do this earlier but had other obligations. I look forward to more participation.	
Great workshop! I look forward to more interaction with QuarkNet.	
I found the VQM quite beneficial	Too much time was spent on the lessons. It didn’t take much time to see the concepts demonstrated.

Seven of the sixteen teachers commented that the institute was beneficial. One teacher stated, “I have appreciated everything I have learned thru the QuarkNet program. I have learned a great deal in the past 4 years – and have developed better teaching skills because of their workshops.” Additional comments were made about KSU: they were accommodating, provided informative and enjoyable lectures and discussions, and gave an opportunity for "us as teachers to network on a state wide level." Teachers also enjoyed the demonstration of the cosmic ray detector and the interaction with other teachers. Four teachers made comments that coded as negative. One teacher felt that although the program was beneficial, there was too much time spent on the "lessons" because the concepts were easily demonstrated. One teacher was unsure of the expectations for him/her because the ideas and opportunities seemed too good to be true. Another was lost because participants did not wear name tags all week long. Still another teacher was "lost" during the laser lab tour

2. Visual Quantum Mechanics Journal Entries - All participating teachers were asked by the professional development facilitators to complete a journal entry for each day of the summer institute. They were instructed to write about the successes and difficulties experienced in the activities and reflect on the professional development provided during the summer institute. Of the 20 participants, only 8 submitted their reflections. The open-ended comments were analyzed by content analysis. Categories were created based on student-related comments and teacher-related comments. Student related comments in Data Table 4.5 have been subdivided into positive and negative statements. Each box represents the comments of a single teacher.

Table 4.5 Student Related Comments from Journals

Activity Number		**Comments**
Activity 1	**Student Related (+) Comments**	This activity is interesting and motivates students. The equipment itself is intriguing: familiar (incandescent and Christmas bulbs) compared to unfamiliar (LEDs) invites further exploration.
		Students can compare the properties of incandescent bulbs and LEDs. An application of this activity is with the Christmas bulbs. If students understand, they will be able to determine that the Christmas bulbs are incandescent lamps.
Activity 2		Students are fascinated when seemingly identical tubes produce different colors of light.
		Students have very low tolerance for frustration, but by the time they compare the data, those who persevered and generated good data would be excited by the results.
	Student Related (-) Comments	
Activity 3		I don't think they would perceive the activity (Activity 3) as a lab.
General to all VQM activities		There is so much written material in the handouts. The majority of the students will not read the narrative parts. They are more likely to just ask me and live with the uncertainty if I decline to explain. I

		don't know how to force them to take the time to read the material unless we read it out loud in class.
		Students will answer them exactly where the question is asked. If I had the activity on word, I would modify the paper to provide space immediately after each question.

Positive student-related comments showed that teachers felt that Activity 1 would be interesting and motivating for students because the equipment is a combination of familiar objects such as incandescent lamps and Christmas light bulbs and unfamiliar objects such as LEDs. If the students understand the concept being taught, they will be able to determine that Christmas light bulbs are incandescent bulbs. In addition, students will be fascinated by the identical gas tubes in Activity 2 because they all produce different colors of light. The negative student –related comments expressed concerns about the amount of reading that the students must do. "The majority of students, even students who are good readers, will not read the narrative parts." In addition, several teachers would like to modify the format for the lab. Student questions are not numbered in the labs. They have question marks instead, which teachers thought might be confusing for the students. One teacher didn't think that "omitting the numbers will fool student into thinking it's not a worksheet." On several pages, the spaces for the answers are at the bottom of the page instead of with the questions. One teacher thought that Activity 3 would not be perceived as a lab by the students.

The teacher-related comments were further subdivided into positive comments, negative comments and comments related to teaching strategies. The positive teacher comments were subdivided by reference made about specific activities. The negative teacher-related comments were subdivided according to reference to equipment verses lab format. Teacher related comments for each of the activities are found in Data Table 4.6.

Table 4.6 Teacher Related Comments from Journals

Activity Number	Teacher (+) Comments	Teacher (-) Comments	Strategies/Modifications
Activity 1	I'm better prepared to use these activities.	The problems were burned out bulbs and voltage meters not working which is hard to solve while assisting students.	Demonstrate the equipment before the students begin the exploration.
	I uncovered some of my own misconceptions which will help me do a better job of addressing them as they show		I could use this activity if I spent more time on electricity.

	up in my students.		
	It was fun to investigate the LEDs. The questions were well written and allow the class to collect data, then share and look at patterns.		
	I liked the VQM activities because I think I can use some of them.		
	I like the way the activity ends with a clue of what we is in the next activity.		
Activity 2	I again had the chance to experience the lab as a "student." I used this lab with my physics class two years ago and it went very well.	It's difficult to read the scales. This lab can be done qualitatively and still understand the concept.	Have students draw the spectral lines they saw in color and giving them the numerical values.
	I enjoyed the opportunity to share with others in my group.	.	With only one power source for the gas tubes, I set up various lab stations with different light sources. I enjoyed the opportunity to share with others in my group.
			I use gas tubes and spectroscopes. I do not go into quite the detail, but we discuss the emission spectra and its applications.
			I could use this activity when I teach about atoms. I have my students use spectroscopes to look at different gases. I bring them out again in the light unit. I like the idea of adding a black light to the types of light.
Activity 3	This activity would be a really useful preparation for Activity 4.		
	I better understand this activity and how to implement is into my physics class.		
Activity 4	It was fun to be able to move the gas tube on the computer after doing it in the lab. I like the way the different gas tubes glowed a different color.	I had a hard time understanding how to set up the energy levels in the first simulation.	Spend a little more time explaining the meaning of the first energy level you start with. There are two possibilities. It's really useful to share ideas with other groups so you can see there is more than one model that explains the observations.
	I learned new features of the		I can do more meaningful

	simulation that will enable me to utilize it more effectively. The activities were very worthwhile in providing me different perspectives that will enable me to better introduce, present, and teach the concepts of quantum mechanics.		demonstrations when discussing light and its behavior and interactions with matter.
	The computer simulation activities were easy to follow and a great activity for high school students.		I think these are advanced for my 8th grader. We discuss energy levels and discuss photon energy, but not in this detail. I think it would be a great activity for high school students.
Activities 5-6	It's very useful to compare absorption and emission spectra. The discussion we had about it is appreciated.		Some could be Earth-like and some not.
	The activity is straight-forward and offers an application students will believe is useful. This is a timely activity with the discussions in the news about habitable planets.		
	Great to show students how the topic is applied to a science problem.		
Activities 7-12	This lab brought us full circle back to LEDs. It really made it much easier to understand why we saw a "smear" instead of discreet lines.	I thought the transition from p. 7-2 to 7-3 was pretty difficult until you explained it.	I answered the homework by putting the energy levels on the computer and looking at the color of the spectrum.
General to all VQM activities	The activity using the emission spectra simulation to demonstrate what LED energy level transitions would look like gave me the impression that those transitions would be very small. It made doing the simulation with the LED's easier to understand. I was glad to have something in writing to show how to manipulate the conduction and valence bands and the energy gap.	I agree that the activities' questions should be numbered.	
	I gained a lot of useful information from these activities.	Students would probably be confused by the question mark method of labeling each question. There were also times when questions seemed to be asked twice.	

	I always learn something from these activities. They are great hands on experiments.	One thing I found frustrating, as a teacher was that the simulations didn't produce the data that are expected. We made the energy levels certain "distances" apart that represent differences in energy between energy levels. Those distances didn't correctly correspond to the energies of light produced by the movement of the electrons between levels. This can be confusion and the error should be changed.	
	I found the investigations in the VQM workshops very interesting.	This content is not emphasized in the state standards. How we find time to integrate the topics of quantum mechanics? I'm interested in the expectations of college professors for their incoming freshmen.	
	I like the idea of exposing high school students to the topics of quantum mechanics.	I have concerns about VQM. First, when and where should this unit be taught and how much does it cost? Second, how does it fit into the state standards?	
General to entire institute	The morning lectures are great. It is nice to see that the more deeply we delve into a subject, the more we don't know. The lectures did help to clear a few things up for me.	The tour was great, but I couldn't hear or understand the guide. It was very cool to see the particle accelerator.	I will be implementing some of these activities into my physics class this coming school year, feeling more confident in my ability to teach the concepts.
	It was refreshing to meet new teachers and reacquaint with previous QuarkNet participants. I learned a lot and I am getting a better understanding of particle physics.		I will take a look at the other VQM activities and see how they fit into my curriculum. I think it is a good program. Perhaps I can use it with my higher achieving students.
	Dr. Weaver is an exceptional educator. My favorite discussion was about dark matter and that scientists do not know what 95% of the matter in the universe is made of. I want to convey that message to my students and tell them that there are a lot of scientific phenomena yet to be discovered.		
	Dr. Bolton's discussion about time dilation was fascinating.		

	I have students ask me about time dilation and now I can let them know that it does actually exist. I also enjoyed the discussion on handedness.		
	The Cosmosphere is continually changing with great exhibits My favorite exhibit was the salt mine.		
	I am surprised at the number of teachers who are getting to modern physics in their courses. My curriculum is very inquiry based and I can't cover as much content. I really enjoyed the idea that we will be talking about the concepts "at the end of the book".		
	The tour of the nuclear reactor was impressive and the student who presented was very knowledgeable.		
	Morning lectures, Feynman diagrams and "right/left" handedness were enlightening. I am learning a lot. It is nice to be able to talk to other physics teachers.		

Positive teacher-related comments for Activity 1 showed that the activity permitted the participants to expose their own misconceptions which will encourage the teachers to do a better job when implementing the activity in the classroom. As one teacher stated, "My seniors will likely experience some of the same things and I will be better equipped to handle their questions and correct some of their misconceptions." In addition, one teacher stated that the activity was fun, questions were well written, and can also be used with 8th graders. Teachers like the idea that data were taken individually and then shared to reveal patterns and that the activity "ends with a clue as to what we will look at in the next activity. Teacher comments demonstrated that Activities 2 and 3 went well. Experiencing them as a "student" showed how the activity prepares the students for Activity 4. Activity 3 introduces energy diagrams. It was "beyond just demonstrating this concept for my students."

Teachers thought Activity 4 was "a pretty cool" activity. They mentioned it was fun because it allows the student to manipulate the gas tubes that they observed in Activity 2 and it is easy to follow so they could also be used in 8th grade science. The teachers had time to learn the many features of the simulations so that it can be utilized “more effectively in demonstrations to my freshman classes and in actual labs with my seniors in physics.”

Activities 5 and 6 are application activities. The teachers thought that comparing absorption spectra with emission spectra was a valuable activity especially when combined with class discussion. It was mentioned that using the spectra to identify habitable planets is timely and fun for the Star Trek fans.

The remainders of the *VQM* activities are grouped together. Although the teachers had time to begin Activity 7, they didn’t finish it. Activities 8-12 were given as handouts only so the comments on these activities were minimal. Teachers liked the fact that the activities went back to the LEDs and re-visited their spectrum because then everything makes more sense. Activities 8-12 also allowed the teachers to learn in more depth the features of the LED simulation so that the conduction and valence bands and the energy gap were more meaningful. Teachers stated that the activities provided an interesting learning experience to accompany the hands-on experiments. One teacher likes “the idea of exposing high school students to the topics of quantum mechanics.” Also the questions that teachers had were addressed during the workshop.

The last category in the positive teacher-related comments is about other activities from the week at the institute. Teachers enjoyed Dr. Weaver’s lecture/discussion about dark matter and the current knowledge in physics. They also enjoyed Dr. Bolton’s discussion about time dilation. As one teacher stated, “I learned a lot and I am getting a better understanding of particle physics.” A teacher suggested that activities in Lyons and the tours of the salt mine and Cosmosphere in Hutchinson were fun and educational.

Some of the negative teacher-related comments expressed concerns about the equipment that was used during activities 1 and 2. There were problems with burned out light bulbs and voltage meters that did not work. Trying to resolve these issues while working with students may be difficult for some teachers. Many participants also had trouble reading the scales in the spectroscopes. Some felt that this was not essential for understanding the lab because there are qualitative methods that can be used with the students. The second area of concern was the format of the activities, in other words, the way they were written. One teacher expressed a concern that; “it didn’t seem that the assignments were always designed with the student in mind.” The energy levels in the first simulation were hard to understand and it sometimes seemed that questions were asked more than once which was confusing and distracting. One teacher felt that the "simulations didn't produce the data that the kids might expect." This teacher felt differences in energy between energy levels and the energies of light produced by the movement of electrons between levels did not match which may cause some loss of credibility for the program. The last concern was time. How does a teacher find the time to integrate quantum mechanics into the current, already full, curriculum? How much time should be spent on this material when it is not really emphasized in our state standards?

In the teacher-related comments about strategies and modifications, teachers stated the science topics that could be enhanced with activities from this program. Several mentioned using *VQM* for an exploration of light and emission spectra as well as their applications. Atomic and quantum theory were also mentioned. One teacher stated that the activities could be used if electricity was taught and another said that activities could be used for "more meaningful demonstrations with my freshman science classes" not only for light but for interactions with matter as well. When using the activities, one teacher would demonstrate the equipment before letting students begin. Another would have the students draw the spectral lines without the numerical values. One teacher sets up stations; incandescent bulbs of different colors, LEDs of different colors, fluorescent light, natural light, and the gas tube with the single power source at another station, so students have access to all the necessary equipment. It was suggested that it also would be useful to share ideas with other groups, particularly when explaining the meaning of the first energy level so that all students can see that more that one model can be produced in the activity.

3. *Visual Quantum Mechanics Email Survey* - All QuarkNet teachers received an email survey at the end of the 2007-2008 school year (Appendix B). The survey was sent to 25 teachers and 20 (80%) of them responded. The first questions on the survey indicated that only 6 of the respondents chose to use the *Solids & Light* program the following school year. For those that did use the program, the subsequent questions determined if they used all the activities in the unit. If not, then they were asked to check-mark the reasons for not using all of the activities. Four of the six teachers that used the program participated in the observational study. Three of the four participants of the observational study did not use all of the activities in the program. The reasons cited for not using all activities included insufficient time, some activities were not

applicable to the district curriculum, schools lacked some of the necessary equipment, and the activities did not align to the state standards.

Those who did not use the program at all were directed to another set of questions. Most of the teachers did not answer the two open-ended questions. However, the answers echoed the information from the institute reflections; the time spent on the program was helpful and they would like more time to work through the entire program. Respondents also were asked to rank on a scale of 1 to 10 the reasons for not using the *VQM* program with number 1 being the most important reason and 10, the least important. Not all of the teachers ranked 1 to 10. Several marked only the top three reasons. The results are found in Data Tables 4.7.

Table 4.7 Reasons for Not Using *VQM* Program

	#times listed as 1	**# times listed as 2**	**# times listed as 3**	**#times cited as a reason**	**Average of teacher ranking**
Doesn't align with state standards		1		3	6
Doesn't fit into my district curriculum	2	2		5	2.4
Lack of access to hands-on equipment	2	1		8	4.1
Student prerequisites were not met	1		1	6	4
Cost of the program		2		5	5.2
Limited access to computers	1	1		6	5.6
Limited time to learn the program	1	5	3	9	3.2
Implementation time is too long		1	2	4	3
Not enough time in the school year	4	2	2	9	2.8

Of the 14 teachers who did not use the program, the most frequently answered responses were limited time to learn the program and not enough time in the school year. In addition, several of the teachers responded that they did not have the hands-on equipment to do the activities. Those answers that ranked the closest to the number 1 in the ranking system were doesn't fit into my curriculum (average = 2.4) and there is not enough time in the school year (average = 2.8).

4. Field Notes – A summary of the researcher's notes, reflections and impressions help to establish themes within the professional development data and how it relates to the teaching strategies used while implementing the unit. The researcher attended the professional development provided by 2 of the new lead teachers. Notes and reflections from these observations were included as part of the professional development data because it was decided that this experience might have affected the way the lead teacher used the program with students.

During the institute, four 90 minute sessions were devoted to *Visual Quantum Mechanics*. The instructor was Dr. Sanjay Rebello who is a collaborator in the Kansas State Physics Education Research Group. The institute participants attempted to experience the *Solids and Light* unit as their own students would do so and then discussed important points for classroom implementation. The teachers began Activity 1 on Tuesday morning. Each teacher was provided a hand-out and the circuit board and multi-meter for recording data. The teachers continued working on Activity 1 on Tuesday afternoon. After a closing discussion, the teachers began Activity 2. This activity was completed on Wednesday morning. When everyone was finished, Dr. Rebello handed out Activity 3 but the teachers did not do the activity. They proceeded directly to Activity 4. Each teacher was given a computer to use for the simulation.

On Thursday morning, after a discussion about the homework questions on Activity 4, the teachers turned their discussion to Activities 5 and 6 which feature applications. Activity 7 allowed the teachers to return to the computer simulations. Hand-outs for activities 8-12 were given to each teacher, but there was not time to look at them as a group. The comments that were recorded are separated into three categories; equipment related, data related, and student related as shown in Data Table 4.8. Each category is further divided according to the activity from the *Solids & Light* unit.

Table 4.8 Field Notes Analysis

	Equipment related	**Data related**	**Student related**
Activity 1	Polarity for LEDs – can try either way.	Data Table – includes the threshold and maximum voltages for all colors of LEDs and the averages.	-If too much time is given, students will be off task. -Could use group discussion to talk about the infrared light we cannot see -Also include uses of these LEDs (remote controls)
	Technical problems: - malfunctioning voltmeters - burned out bulbs - getting small wires on Christmas bulbs into the circuit	Note change in color change of incandescent light	Use some info from LED to compare to Christmas lights. Do the high and low for averages to eliminate polling all groups
	Concern: Cost of program is $250	Data table for Christmas lights -Should not be a trend -Caused by our sensitivity to light	Conceptual concerns: - trend in Christmas bulbs - energy/light relationship - maximum voltage =

			number of photons - threshold voltage = energy of photons - Do you tell what the ranges should be? No
			Student trouble -Little adjustments -Holding button down; small button - Look at LED from above for better view
Activity 2	Difficulties with spectrometers: -It is hard to see the scales and numbers -Must be close to light to see anything -Pen light at right angle can illuminate scale	Data is discussed but not question by question.	Can discuss with students the relationship between wavelength and energy
	Possible Solutions: -Take the time to learn to see the scales and numbers - must be close to light source to see them - Pen light at right angle can illuminate scale - Use flex-cam on the spectroscope and project	Questions are qualitative LEDs = band with brightest around color of LED (all colors are still present)	Could add light sticks to show light in liquids
	The class discussion included the difference between types of spectroscopes. Several have numerical scales but only the most expensive have the eV energy scale. The lab is written such that both scales are used in the data.		
	Assumptions - tubes have same gas density; apparent brightness is actually used		
Activity 3		Hand out but teachers skip doing this?	
Activity 4	Each teacher has own computer for this simulation	Reactions: -Scale is small -Energy jump was off .2 from scale above -Distance between lines was a good visual	LED model with "smear" of color in spectrum may need some scaffolding.
	Some confusion on the lines on the program – read directions carefully. (Some teachers just jumped in).	There's more than one way to draw the energy differences – both can be considered correct	
		We really don't know what is happening – this is our best guess	Are questions like: "Does this **really** happen?" going to be asked by the students?
			Discussion of the homework activity which is an

			application for spectral analysis
Activity 5		Discussion at beginning included a diagram on the board to clarify how an absorption and emission spectrum differ	This is an application activity
Activity 6	Need transparency of planet's atmosphere		A teacher could make additional planets so that different groups have different results
Activity 7	Back to the computer program		May be more than what typical students would do
			Teachers moved through faster than what students would do
			Discussion of timing – where to put nuclear chemistry/atomic physics
Activities 8-12	Hand-out for activities 8, 9, 10, 11 and 12 for each teacher		

As mentioned, the equipment needed for Activity 1 included a circuit board, incandescent light bulbs, Christmas bulbs, LEDs, and a multi-meter. Teachers had problems with burnt out bulbs and voltmeters that did not function properly. Since the lights were turned out for better data collection, it was difficult to see the small wires on the Christmas bulbs to insert them into the circuit board. The LEDs are polarity specific but it is a learning experience to try putting them into the circuit board both directions. For Activity 2, everyone used spectroscopes to view gas lamps and the lights on the circuit boards. It takes some time to learn how to see the scales and numbers in the spectroscopes. One must hold the spectroscope close to the light source. It helps to hold a pen light at a right angle to provided illumination for the scale. The class discussion included the differences between types of spectroscopes. Several have numerical scales but only the most expensive have the eV energy scale. The lab is written such that both scales are used in the data. One suggested solution was to use a flex-cam on the spectroscope and project the image on the screen. In addition, light sticks could be included to show light in liquids. The discussion also included the assumption that the gas tubes have the same gas density while the apparent brightness is actually causing the differences.

Activity 3 does not include any lab equipment as it is a thought process to learn about energy diagrams. Activity 4 uses a computer simulation called the "Spectroscopy Lab Suite." Activities 5 and 6 are application activities. Activity 5 uses the "Spectroscopy Lab Suite" and

Activity 6 needs the spectrum of a planet's atmosphere. Teachers could make additional planets so that different groups have different results. Activity 7 goes back to the computer simulation.

The data collection and discussion for Activity 1 begins with the threshold and maximum voltages for the incandescent bulb and all colors of LEDs and their averages. These data were placed on the board during the discussion. It was noted that a color change does occur in the incandescent bulb as the voltage increases. The discussion also included the answers to the questions in the lab. Then the activity continues with testing of Christmas bulbs of different colors. These data were also placed on the board during the class discussion. Some points of discussion were to be sure to use some of the information from the LEDs to compare to the Christmas bulbs. It was suggested that one could use only the high and low values recorded to determine approximate averages in order to eliminate polling all the group, and that the data for the Christmas bulbs should not be expected to show a trend. It is also important to discuss difference of energy values between LEDs and Christmas bulbs. Mistakes can be made within the data because of differences in our sensitivity to light. It was noted that if one observes the LED from above rather than from the side, the results are better. For Activity 2, Dr. Rebello discussed the lab questions with the group but did not follow the lab question-by-question. The questions were qualitative in nature. The spectra for the LEDs have a large band consisting of all colors with the brightest area around the color of the LED. The data for Activity 3 was not discussed because the participants skipped over this activity.

When Activity 4 began, some teachers just started immediately without reading the directions and as a result, there was some confusion. Once everyone figured out the program, everything seemed to go smoothly. The group discussion of Activity 4 included the perspective that the scale for the spectrum was too small and the energy jump was 0.2 above the top of the scale. However, the distance between the lines was a good visual representation. There was a reminder that we really don't know what is happening – this is our best guess. In addition, there is more than one way to draw the energy differences and both should be considered correct. At the beginning of Activity 5, there was a discussion of the difference between absorption spectra and emission spectra. A diagram indicating production of the two types of spectra was drawn on the board for clarification. Data for activities 6 and 7 were not discussed.

Comments placed in the student related category are those ideas that might be important to a teacher as the program is implemented in the classroom. Dr. Rebello models a strategy when he gives the teachers a heads-up before the first class discussion of data in Activity 1. If students are off task, then too much time has been given for the data collection. During the discussion of data, it was pointed out that one of the LEDs did not seem to work but it is actually an infrared light which requires additional equipment. This information could also be discussed with high school students. It also would be appropriate to discuss the uses of LEDs in equipment such as remote controls when discussing the data with students. It would be beneficial to remind students to look at the LED data when collecting the Christmas bulb data. When calculating average values with the students, a time saving technique is to look at the high and low values only instead of polling all the student groups.

The discussion also included the types of problems that students might encounter. The voltage adjustments are very small. Holding the "on" button on the circuit board may be difficult because it is so small. The data for the Christmas lights and the LEDs should not show the same pattern but they show how energy and light are related. The maximum voltage shows the number of photons and the threshold shows the energy of the photons. Teachers should be sure to check that students understand these concepts.

The field notes for the two professional development opportunities provided by the QuarkNet lead teachers are difficult to compare to those of the summer institute and to each other. The session held at KATS Kamp was 50 minutes long. Its purpose was to inform teachers about the upcoming opportunities for longer sessions. It emphasized the fact that the workshops were free, that the program was based on the learning cycle, and gave an overview of the *Visual Quantum Mechanics* program. The "Spectroscopy Lab Suite" and the "Waves of Matter" simulations were demonstrated and several student hand-outs were distributed as the program was described.

The second professional development opportunity occurred on May 9, 2008 at Seaman High School. It began at 9:00 am and ended at 2:00 pm. The participants worked through and discussed Activities 1, 4, 5, and 6 from *Solids & Light* and Activity 2 from Luminescence. They also explored the computer simulations for the "Energy Diagram" and "Light Diffraction" activities that are in other *VQM* units. The activities were keyed to the Kansas State Science Standards. For example, the entire *VQM* program addresses Standard 1 which is the concept of inquiry learning. Several activities in *Luminescence* and *Solids & Light* address Standard 2B.5.5

which shows the relationship between energy and wavelength. Both sessions briefly described the QuarkNet program and its connection to Kansas State University.

5. Documents – The summer institute teachers were provided with a handout for each of the twelve activities in the *Solids & Light* unit. In addition, there are teaching resources provided on the CD when the *Visual Quantum Mechanics* program is purchased from Ztec. These resources include the student handouts as well as a teacher's guide. The information given in the teacher's guide includes the objectives, student prerequisites, teaching hints, and equipment needed for each activity as well as an answer key and test questions. A site license for the computer simulations is also provided with the purchase of the program.

Instructional Strategies

Instructional strategies of four teachers were observed at four different schools. The schools will be referred to as School A, School B, School C, and School D. Teachers will be identified as Teachers A, B, C and D. Five sources of data will provide information on the instructional strategies used by participating teachers as they implement the *Solids & Light* unit: (1) a participant information form, (2) the Instructor Questionnaires A and B which were completed by participating teachers, (3) interviews with participating teachers, (4) the Classroom Observation Protocol used for observations of participating teachers, and (5) researcher field notes.

1. Participant Information Form – At the beginning of the study, the teachers who volunteered to participate in the in-depth observational study were asked to complete this form (Appendix B). It provides demographic and professional information about the teachers who participated in the observational study that was previously presented in Chapter 3. In addition, the Participant Information form shows the extent to which the participants have used computers and inquiry learning activities prior to beginning the *Solids & Light* unit. Data Table 4.9 indicates the responses related to computer usage for each of the participants of the observational study.

Table 4.9 Teacher Computer Use

To what extent do you incorporate computers into your physics teaching?	Teacher A	Teacher B	Teacher C	Teacher D
Computers are not available to me at school.				
Computers are available but are not currently being used in my physics course.				
Computers are used by me for instructional purposes in the classroom	X	X	X	X
Computers are used by me for instructional purposes in the laboratory.	X	X		X
Computers are used by students in the classroom.	X	X	X	X
Computers are used by students in the laboratory.		X	X	X
Computers are used by me for grading or record-keeping	X	X	X	X
Other uses (please specify)				

All four of the teachers in the observational study use computers in their classroom for instructional purposes and for grading and record keeping. Students use the computers in the classroom as well. Three of the four teachers use the computers for instructional purposes in the lab and the students in three schools use computers in the laboratory. Data Table 4.10 demonstrates the data for inquiry learning.

Table 4.10 Use of Inquiry Learning

To what extent do you use inquiry activities in your physics teaching?	Teacher A	Teacher B	Teacher C	Teacher D
I almost never use inquiry activities in my classroom.				
I seldom use inquiry activities in my classroom.				
I sometimes use inquiry activities in my classroom.				
I often use inquiry activities in my classroom.	X	X	X	X
I very often use inquiry activities in my classroom.	X			
a. Activities are mostly guided inquiry.	X		X	
b. Activities are sometimes guided and sometimes open-ended.	X	X		
c. Activities are mostly open-ended inquiry.				
d. Other uses (please specify)				

The data indicate that all of the teachers in the observational study use inquiry activities in their classrooms often. The activities are a combination of guided inquiry and open-ended inquiry. This information can be compared to the students' perception of the lab environment as well. This comparison will be made after the results of the Science Laboratory Environment Inventory are explained in the student data.

2. Instructor Questionnaires - Teachers who volunteered to participate in the observational study were asked to complete the Teacher Questionnaires A and B (Escalada, 1997) as they completed activities with their students. Questionnaire A (Appendix B) discussed Activities 1-6. In these activities, the students compare incandescent bulbs with LEDs, observe emission spectra of bulbs, LEDs and gas lamps, and complete energy diagrams. They use a computer simulation to combine the information from the previous activities and then complete two application activities. Questionnaire B (Appendix B) discussed Activities 7-12. These activities allow students to use energy level diagrams to understand the light spectra of LEDs and produce an energy level model for LEDs. In addition, they use energy bands and gaps to explain the properties of incandescent lamps. The two optional activities allow the students to calculate Ohm's Law and Planck's constant using data from the light sources.

All of the teachers completed Questionnaire A. Only Teacher D completed activities beyond activity 6. As a result, Teacher D completed Questionnaire B and the other three teachers answered only the last questions that were over the entire unit. The categories for the analysis of the open-ended questions were determined by the content of the items asked by the questionnaire. The topics include the physics concepts learned, whether prerequisites were met, and difficulties with the unit. The answers for these categories are found in Data Table 4.11.

Table 4.11 Concepts Learned and Difficulties: Activities 1-6

	Physics concepts learned	**Prerequisites met**	**Difficulties with unit**
School A	-The relationship between energy and light -How to use conservation of energy to explain line spectra	Yes	Not really, once they got comfortable seeing energy diagram and spectrum they really accelerated through the material.
School B	-Atomic spectra (bright line spectra) -Incandescence and continuous spectra -Electron energy transition -Photon energy and brightness	Yes	No significant difficulties

School C	-Relationship between color of light emitted and voltage. -How an LED works -Transitions correspond to an emission or absorption of a photon; they responded with correct answer, but I'm not sure they understood	Yes	The experiments presented no difficulties. The concepts were understood at a basic level – no deep understanding of physics concepts was achieved.
School D	-Energy relationships -Different between "continuous" energy transitions and discrete transitions -Practical applications of quantum mechanics	Yes	Sometimes would confuse brightness/intensity with color and energy of emitted light

The teachers believed that the physics concepts learned by their students included energy relationships, particularly the relationship between light color and energy, and the light spectrum. Teacher C thought that the students could answer the questions correctly but may not have understood the concept completely. Teacher D thought that students learned the practical applications of quantum mechanics. All four teachers felt that their students had the required prerequisites for the program. There were no significant problems with the unit although Teacher D thought his students sometimes confused brightness with color and energy of emitted light.

Questionnaire A also requested the teachers to complete a data table that asked for the amount of time spent on each activity and any modifications made by adding or omitting materials to the activities. The results of these data are found in Data Table 4.12

Table 4.12 Time and Modifications: Activities 1-6

Activity	Time Required	What, if anything, did you omit from the activity?	What, if anything, did you add to the activity?
1. Exploring LEDs and Lamps	A. 60 min B. 60-80 C. 45 min D. 45+ min	A. Nothing over Hund B-C: Christmas tree lights D. Nothing	A-C: Blank D. Didn't use diff. set up for some stations – used DC power supplies w/digital read-out.
2. Exploring Light Patterns	A. 60 min B. 50-60 C. 120 min D. 45 min	A-C: Blank D. Nothing	All Blank
3. Introducing Energy Diagrams for Atoms	A. 45 min B. 50 min C. 25 min D. 45 min	A. Nothing over Hund B. Blank C. Application questions D. Nothing	A. Video: Bohr Model of the Atom and Spectrum (30 min) B-D: Blank
4. Understanding the	A. 45 min	A–C: blank	A. Video: Applications of

Spectra Emitted by Gas Lamps	B. 50-60 C. 45 min D. 30 min	D. Nothing	spectrum (30 min) B-D: Blank
5. Applying Spectra and Energy Diagrams to Learn About Stars	A. 30 min B. NA C. 45 min D. 20 min	A-C: Blank D. Nothing	All Blank
6. Should Activity 6 be listed with the first 5 activities?*	A. 30 min B-C: NA D. yes	A. Blank B-C: NA D. Blank	A. Blank B-C:NA D. Blank

*This space should have been the title for activity 6. Teachers answered it as it currently is presented.

The average amount of time necessary to complete Activity 1 was 55 minutes. Two of the four teachers did not do the Christmas light portion of the activity. The teachers did not add anything to the activity; however, Teacher D modified the equipment by using DC power supplies with digital read-out. As a result, students moved from station to station rather than assigning every lab group to a station with a complete set of equipment. The average amount of time for Activity 2 was 70 minutes. Nothing was omitted or added by any of the teachers. Activity 3 took about 42 minutes to complete. Teacher C omitted the application questions and teacher D added a 30 minute video called "Bohr Model of the Atom and Spectrum." Using the computers for Activity 4 took about 45 minutes. The teachers did not omit anything from this activity. Teacher A viewed a 30 minutes video called "Applications of Spectrum." It took about 30 minutes to complete Activity 5. Teacher B did not complete this activity and the other teachers did not change the activity in any way. Activity 6 also took about 30 minutes to complete. Teachers B and C did not complete this activity. The other teachers used the activity as it was written.

Questionnaire A also asked the teachers to rate the effectiveness of the activities in meeting the objectives of the instructional units. Each activity has multiple objectives referred to as 1-1, 1-2, 2-1, etc. Teachers rated the effectiveness of the activities on a 5-point scale between 5 (very effective) to 1 (not effective). The results are found in Data Table 4.13.

Table 4.13 Effectiveness of Meeting the Objectives: Activities 1-6

Objective	Rating Average	Evidence
1-1 Describe and compare the characteristics of light emitted by light emitting diode (LEDs) with that of an incandescent lamp and Christmas lights.	4.5	a. None given for all b. Compare/contrast table c. Students readily noticed differences in voltage ranges of each d. Did well on Q RE: determining type of light Christmas bulb was.
1-2 State the turn-on (threshold) voltage for LEDs and incandescent lamps, including Christmas lights.	4.0	b. Threshold voltage table c. Blank d. Understood TV but didn't dist. B/T types
1-3 Compare the threshold voltages for LEDs of different colors, and for incandescent lamps of different colors.	3.75	b. Threshold voltage table c. Some of the colors of LEDs were too similar to differentiate the threshold voltages d. Same as above
1-4 Describe and compare the effect of changing the voltage applied to LEDs and incandescent lamps on the intensity and color of light emitted by these devices.	4.25	b. Activity 1 questions c. Blank d. Spectral drawings of each gas but still confused intensity and energy
Average for Activity 1	**4.13**	
2-1 Use a spectroscope to observe, describe, and identify the characteristic spectra emitted by gas lamps, incandescent lams, and LEDs.	4.5	b. Example spectra c. Blank d. Provided accurate spectral drawing of each gas
2-2 Observe the color changes of an incandescent lamp as the voltage is changed.	4.0	b. Activity 1 questions c. Blank d. Often referred to brightness but not color
2-3 Describe and differentiate between the energy of light related to color and that related to intensity.	3.75	b. Activity 1 questions c. We had to go back and make observations a 2nd time to realize the differences. d. Same as above
2-4 Present data for the spectra of the various devices.	4.25	b. Example spectra c. Blank d. Same as 2-1
Average for Activity 2	**4.13**	
3-1 Sketch an energy level diagram for an atom.	4.5	b. Activity 3 and 4 c. Blank d. Did well on these questions too
3-2 Understand how changes in an atom's energy are related to the emission of light.	4.25	b. Activity 3 and 4 c. Blank d. Most made this connection
Average for Activity 3	**4.38**	
4-1 Using the Atomic Spectroscopy computer program to construct a possible set of allowed energies for an electron when given the spectral lines.	4.75	b. Activity 3 c. Students easily mastered program d. As I watched them use this they didn't need much help
4-2 Explain why gas spectra leads to the conclusion that the atom's electrons can have only certain values.	3.5	b. Activity 3 questions c. Blank d. Still not sure that they understood
Average for Activity 4	**4.13**	

5-1 Explain how absorption and emission spectra are related.	4.0	b. Activity 3 questions c. Blank d. Most could explain this w/o help
5-2 Identify a set of absorption lines belonging to a particular element.	4.0 Only three of the teachers did this activity	b. NA c. Blank d. ?
5-3 Explain how scientists can determine the composition of objects like a star.	2.75 Only three teachers	b. NA c. Blank d. As I looked over and graded these, they seemed to confuse what's required for like vs what's not or, especially what's toxic
Average for Activity 5	**3.58**	
6-1 Describe how absorption spectra can be used to identify gases in the atmosphere of a distant planet.	3.5 Only two teachers	b-c. NA d. Same as above
6-2 Have a better understanding of the relation between absorption and emission spectra.	3.0 Only two teachers	b-c. NA d. Same as above
Average for Activity 6	**3.25**	

The majority of the objectives had a rating of 4 or higher which reflects that the activities were effective in the judgment of the teachers. Activities 5 and 6 were less effective than the others. The average value for Activity 1 in terms of rating the objectives was 4.13 which show that teachers perceive Activity 1 as effective in meeting the objectives. The average value of the rating for Activity 2 objectives was also 4.13 which show that the teachers felt that Activity 2 met the stated objectives. The highest average rating of 4.38 was determined for Activity 3 indicating that teachers believed it was more effective than the first two activities. Activity 4 is consistent with the previous activities with an average rating of 4.13. Activity 5 had the individual objective with the lowest rating (2.75 for Objective 5-3) which lowered the average rating for Activity 5 to 3.58. The average for Activity 6 was the lowest average at 3.25 on a 5-point scale which is satisfactory. Schools B and C did not get to this activity so only two teachers completed this activity. This circumstance renders the data less accurate.

Questionnaire B asked similar questions as the first questionnaire but covered activities 7-12 so the categories for the analysis are the same. Only one of the teachers did any of these activities. His responses are found in the Data Table 4.14.

Table 4.14 Concepts Learned and Difficulties: Activities 7-12

	School D
Physics concepts learned	How LED's work in that the different energy transitions take place as follows: 1) the valence and conduction bands have many energy transitions; 2) there is a specific amount of energy which electrons must "cross" in order for the LED to give off light which corresponds to the energy value of the energy gap.
Prerequisites met	Yes.
Difficulties with unit	At first, only using the spectroscopy lab suite for simulating how an LED works and then some misunderstandings regarding how to manipulate the bands and energy gap for getting specific spectra for various LED's.

Teacher D believes that his students developed an understanding of how LEDs work, specifically as influenced by the valence and conduction bands and the amount of energy needed to cross the energy gap to produce the visible light. He also states that each of the activities required 30-45 minutes to complete. Activities 11 and 12 were not completed by his students. He did not omit anything from the activities that were done by the students. He did add a short lab called "Quanta of Quarters" in which the students mass a film canister containing different numbers of quarters to determine the mass of one quarter. Teacher D's assessment of the effectiveness of the activities in meeting the objectives is in Data Table 4.15. Each activity has multiple objectives referred to as 7-1, 7-2, 8-1, etc. The effectiveness of the activities was rated on a 5-point scale where 5 was "very effective" and 1 was "not effective."

Table 4.15 Effectiveness of Meeting the Objectives: Activities 7-12

Question	**Rating**	**Comments**
7-1 Describe why closely spaced energy levels are needed to explain the spectra of an LED.	4	
7-2 Explain how the difference in energy between the upper set of energy levels and the lower set is related to the color of light emitted by an LED.	3	
7-3 Define the terms "valence band" and "conduction band".	4	
8-1 Describe how the energy bands in a solid lead to the creation of white light.	2	My students seemed to struggle with this; they wanted to consider white light as highest energy or least energy rather than the mixture of all the energies.

8-2 Understand the roles of conduction and valence bands in a solid.	3	
9-1 Be familiar with the energy bands and gaps in LEDs.	4	
9-2 Understand the role of energy gaps in determining the threshold voltage of an LED.	4	
10-1 Explain the effect of an applied voltage upon the energy bands in LEDs.	3	
10-2 Understand how LEDs produce light.	3	
10-3 Explain why LEDs have the properties described in the prerequisites.	3	
11-1 Understand the limitations of Ohm's Law in explaining the I-V graphs of the incandescent lamp and the LED.	Did not do	
Average score for objectives combined	**3.3**	

Most of the objectives were rated as a 3 or a 4 on the 5-point scale. Those with a rating of 4 included objectives 7-1, 7-2, 9-1, and 9-2. Objective 8-1 received the lowest rating of 2. The students struggled with the concept of white light being produced by a mixture of all of the energies. The average rating for all objectives combined is 3.3 which on a 5-point scale is satisfactory.

The last page of Questionnaire B was composed of general questions about the entire program so all teachers were asked to answer these questions. There are five categories for this analysis based on the questions that were asked on the questionnaire: the comfort level of the teacher with the content, the placement of the program in the curriculum, recommendations to other teachers, useful support materials, and helpful *VQM* training activities. The responses are found in Data Table 4.16.

Table 4.16 Questionnaire B - General Questions: Activities 1-12

	School A	**School B**	**School C**	**School D**
Comfort with content	Yes, not much review beforehand	Yes, but had little understanding of LEDs beforehand.	Yes, after working through them. Better next year	Yes.
Placement in curriculum	*VQM* followed energy and energy conservation. After *VQM*, physics topic papers	1-6 could be used when studying atomic structure. Activities 7-12 could be used when studying electricity.	This unit can stand alone. Maybe **after** the CASTLE electricity unit.	Just after electricity and magnetism. Afterwards, try to work in some nuclear physics or special topic such as relativity.
Recommendations	Yes, it really ties	Yes, because the	Yes, I believe it	Yes, because it

	in chemistry and physics and energy conservation.	activities are inquiry based.	introduces students to current technology (LEDs).	provides a very observable way of teaching an abstract concept using very simple mathematics and very good computer simulations.
Useful support materials	Having activity handouts and an instructor's guide let me the answers so I know how detailed to go into this.	The teacher guides are very helpful.	The teacher's guide that came with the software is **very** helpful.	Most helpful to me and my students were the computer simulation manuals.
Useful training activities	Just being introduced to it and seeing the different aspects of the curriculum. Maybe for the future we can do other activities as well.	Actually working with the materials/equipment .	While the *VQM* training was interesting, it was **too** rushed, and not enough of the activities were done. I finally understood the materials while trying to teach it.	Exploring LEDs and lamps; introducing energy diagrams; and understanding spectra. The simulations involving the LED energies were most helpful in understanding quantized energy transitions and relationships.

Most of the teachers were comfortable with the content covered in the *Solids & Light* units. One teacher stated that she would be more comfortable next year since working through the activities during this research study. Each teacher had a different place for the unit in the curriculum. One would place it before energy and energy conservation. Two teachers mentioned placing it after electricity although it could also be placed at the beginning of the year. Another teacher would teach Activities 1-6 in chemistry with atomic structure and Activities 7-12 in physics with the electricity unit. All of the teachers would recommend this program to other teachers. Reasons cited include the inquiry based activities and that the program teaches abstract concepts by means of "easily observable activities." The most useful support material for all the teachers was the teacher guide. It contains all of the student hand-outs as well as the answers for all the activities. The most useful activities during the training varied from teacher to teacher. One liked "seeing the different aspects of the curriculum." Others felt that working with the equipment and simulations was most helpful.

While most comments were positive, the last teacher felt that the training was "too rushed" and not complete. By actually teaching the unit teachers discovered the connections between the activities. There is a correlation between the activities that were completed during the professional development and the activities that were completed in the classroom. During the professional development, Activities 1-7 were completed and/or discussed in detail. In the classroom, all four teachers completed Activities 1-4, only three teachers completed Activity 5, only two teachers completed Activity 6, and only one teacher completed Activity 7 or beyond. Teachers used in the classroom those activities that they had time to use and discuss during the professional development.

3. Interviews – An interview was conducted with each of the four teachers who participated in the observational study after the first classroom observation and a second exit interview was conducted when the unit was complete. The questions for these interviews are found on the observation protocol (Appendix B). Data from the interview completed after the first classroom observation reveals the teacher's reflection on student progress. The responses to the open-ended questions are divided into three categories based on the topics that emerged from the teachers' responses. These include student related comments, teaching strategy related comments, and class timing comments which describes if the teachers are where they had planned to be at that point in time.

The student and strategy related comments are further divided into positive and negative responses. The responses can be found in Data Table 4.17.

Table 4.17 First Teacher Interview Responses

Student related Positive (+)	**Student related Negative (-)**	**Class timing**	**Teaching Strategies Positive (+)**	**Teaching Strategies Negative (-)**
Teacher A				
Today's class was more self-guided than normal. It was typical because students think through things themselves so they ask better questions.		Yes, however Activity 2 took longer than planned.	The spectroscopes took time. I thought about using photographs projected on the TV but decided against it. The concepts not the values are important.	
		Next is Activity 4 and the goal is to		

		finish 6.		
Teacher B				
	It was typical for the last week of school. Usually students are less distracted. Normally, would have enough supplies for smaller groups.	They accomplished most of it with the encouragement of the teacher.	The instructor has done these activities before this but this is the first year to use the circuit boards.	Students needed guidance to be sure that they write down the data and answers to the questions.
		The next steps are activities 3 and 4.		The 5th hour class did not get to the compare and contrast table so the eV concept has not made the connection yet.
				It would be nice to be able to modify the forms.
Teacher C				
It was pretty typical. Students usually explore with the teacher as part of the group of three.		No, the class needs to return to the dark room for additional data before answering the rest of the lab questions.		The instructor has not worked with the gas tubes or spectroscopes before.
		They will finish Activity 2. Then they will use the lab suite on the computer.	This will allow them to see the eV values more clearly. Students will use the teacher's lap top for these activities.	
			The program has helped the teacher better understand the content.	
Teacher D				
		The lecture was longer today than normal.	The students needed more information because the content is more abstract.	
		The students will discuss the homework and class data. Then the students will start Activity 2.	Try to stay with the same routine such as the "Do Now" activity, followed by some notes. The goal is to complete one activity during each class period.	
			The computer lab is on a cart. Each lab station has a computer.	

Student related responses reflect the differences in the schools. Teacher A felt the students were more self-guided on the day of the observation. They typically think through activities themselves which improves the quality of their questions later. Teacher C felt the students were typical on the day of the observation as well. In a small school, the students may interact with the teacher more. Teacher B felt the students were not typical because it was close to the end of the year and they seemed easily distracted. In addition, one of the circuit boards was missing during the afternoon session so the lab groups were larger that normal.

Positive comments about teaching strategies indicate a variety of ideas. Teacher A felt the spectroscopes take time but are valuable in teaching the concepts. Teacher B used the circuit boards for the first time even though she had previously used the *VQM* program with her students. Teacher C thought that the eV values were more clearly understood on the spectrum and that the program helped her understand the concept as well as her students. Teacher D felt the concepts were abstract so he added a longer lecture presentation than usual at the beginning of the unit. He had routines such as a "Do Now" activity at the beginning of each block that he continued to follow. Activity 4 requires computers. Two of the schools had access to computer carts so that each group of students would have a computer. School C, with only 2 students in class, would be using the teacher's laptop. In School B, the students had individual laptops that were checked out from the school.

The responses in the "class timing" category showed that the teachers were progressing through the unit in the order of the activities. Two of the teachers stated that Activity 2 took longer than they had anticipated. School C had to move the class to another room to achieve the darkness needed for this activity and then discovered that another trip would need to be made because they had missed collecting part of the data.

The exit interview indicates the relationship between the implementation of the program and the professional development as well as the teacher's other previous experiences. The categories for analysis are based on the questions that the teachers were asked at the end of the unit. Topics for the questions are: experiences that influence teaching strategies, the effectiveness of the *VQM* training, how the *VQM* is related to the state science standards, whether the teacher had been trained in "modeling physics", the cost of program implementation, and any additional thoughts that presented themselves. The outcomes of the exit interviews are found in Data Table 4.18.

Table 4.18 Teacher Exit Interview Responses

	Teacher A	Teacher B	Teacher C	Teacher D
Influences on strategies	Most influenced by his cooperating teacher who used inquiry based activities – a philosophy that they shared	Research that supports active inquiry	In a search to help a student, a colleague introduced her to a program called 4-Mat which emphasizes different teaching styles.	The Learning Pyramid that shows that students learn less during lecture and more during activities.
VQM training	The training was an introduction. More time is needed on implementation especially reading to become more comfortable with the program.	Yes, she had already used the program with students and was ready to try it again.	No, activities were not taken in context with the entire unit.	Yes, he had done VQM before. However, every time you use the unit, you always learn something new.
Science Standards	We need to be able to justify with the Standards to use this. There are some hard to reach standards that are covered by this program.	It didn't – except maybe the standards on inquiry.	It didn't.	He didn't worry too much about the standards. The students are all seniors who will not be assessed.
Modeling	He attended a modeling workshop. The modeling is based on the learning cycle.	Modeling made the unit easier to implement.	She used the unit as it is written. Modeling takes a lot of time.	He has not been trained in modeling but learned some of the techniques from a colleague. He did not use with the VQM.
Cost of program	Not much; some miscellaneous supplies and reading time.	Nothing monetarily	Nothing monetarily but wanted more time to work through the entire unit.	Nothing monetarily but spent more time reading and preparing
Additional thoughts	Would like to see some training on some of the other units in the VQM program	Would like to "tweak" the activities to match the individual teacher and students	The teacher's guide is good. Some creativity was needed to do the activities with a small number of students.	Students seemed to pick up the concepts quickly

The previous experiences that had most influenced the teaching strategies of the participants were as varied as the teachers themselves. Teacher A was most influenced by his cooperating teacher. The philosophy of both gentlemen was based on learning by inquiry. Student teaching had given Teacher A experience with inquiry based activities. Teacher B was most influenced by the research that supports active inquiry. She stated that "Students learn better when they are active." Teacher C was most influenced by the 4-MAT program. She became familiar with the teaching and learning styles in her quest to help a particular student. The Learning Pyramid influenced Teacher D. When he realized that students learn less during lecture and more during activities, he moved his teaching strategies to more inquiry based activities.

When asked if the institute prepared them to implement the *VQM* program, two of the teachers answered yes and two of them answered no. Teachers A and C felt that more preparation was needed on their part. Teacher A needed to do additional reading which he found enjoyable. As a lead teacher, Teacher C felt that preparing her own workshop improved her comfort level. Teachers B and D were comfortable with the program even though Teacher D also commented in responding to a later question that he spent additional time reading about quantum physics before implementing the program. It is interesting to note that Teachers B and D had also used the *VQM* program previously which may have influenced their comfort level.

Three of the four teachers do not believe that the *VQM* program aligns with the Kansas State Science Standards. They are teaching the *VQM* unit after the students have been assessed in science so the science assessments do not influence their decision to use the program. Teacher A however feels that alignment to the standards is important. He said, "We need to be able to justify with the Standards to use this. There are some hard to reach standards that are covered by this program". As a lead teacher, Teacher A prepared a PowerPoint slide presentation that illustrated the specific alignments of the *VQM* program to the Kansas Science Standards.

All of the teachers were familiar with Modeling Physics. Teachers A, B and C have all attended modeling workshops. Teacher D learned about modeling from a colleague. Teacher A felt that both modeling and *VQM* are based on the learning cycle so he uses both in his classroom. Teacher B incorporated the questioning techniques and white-boards from the modeling. Teacher C did not use the modeling. Teacher D may try to incorporate more modeling next year.

When asked about the cost of the program, all of the teachers answered that it was very little. All of the participants are lead teachers. As such, the QuarkNet program provided them with the *VQM* program. Circuit boards, gas lamps, and other lab materials could be borrowed from KSU if they did not have them in their classrooms. Teachers A, C, and D mentioned that time was a factor in the implementation of the program. Additional reading and planning was done before they were ready to use the program with their students.

Additional comments about the *VQM* program reinforce other data. Teacher A would like more training on the other units in the *VQM* program. Teacher B also expressed this interest after her *VQM* presentation at KATS Kamp. Teacher B would like to be able to "tweak" the activities to meet individual and student needs. This comment also appeared in the initial interviews and journal writings. Teacher C, with a class of two students, needed to be creative in some of her teaching strategies. She had to take the students to another room to have the darkness needed for the gas tubes. The students built a black paper tent to do the activities with the circuit boards. Her students had to take all of the data instead of sharing "class data." Teacher D felt that his students learned the concepts quickly. This may have been influenced by the fact that the students had done other computer simulations in class.

4. Classroom Observation Protocol - The Classroom Observation Protocol found in Appendix B (Young, 1995) was used to collect data on the instructional strategies used by the four teachers participating in the observational study (Teachers A – D). The classroom observation protocol was modified from its original format by the researcher. A frequency chart was added to plot activities of the students at specific times. The specific inquiry-type behaviors were developed from a list of essential features of classroom inquiry developed by the National Research Council in 2000 (Cianciolo, Flory, and Atwell, 2006). In addition, some questions were modified to specifically address *Solids & Light*. The researcher did a personal classroom visit with each participating teacher. This classroom observation was completed as the teachers implemented one of the first four activities in the *Solids & Light* unit. The remaining class sessions for the unit were videotaped for the observation. Observational data provide a wide variety of information regarding the physical environment, the teaching strategies, student activities and materials used to teach the unit as well as assessment strategies used to determine student learning.

For analysis purposes, the Classroom Observation Protocol has been divided into four sections; informational questions, the frequency chart, the typology and the reflections. The informational questions are inquiries about instructional strategies, student activities, and materials that provide the researcher with a variety of choices. The researcher checked all choices that applied. The frequency chart tallies student activities throughout the class. The typology reflects the researcher's interpretation of where the teachers' strategies fall on a set of continua. The left side of each continuum is more traditional and the right side is more inquiry based. The last portion of the protocol is a series of questions that generate the reflection of the researcher. The instructional strategies of the four teachers were analyzed based on their progress through the activities and implementation of each activity was analyzed to show similarities and differences between the teachers.

The categories for the analysis of the informational questions were determined by the content of the questions asked by the protocol. To determine teaching strategies recorded on the frequency chart, one must interpret what the teacher is doing. For example, if the students are listening and taking notes, then the teacher must be talking. When the students are interacting with the teacher, then the teacher is using class or small group discussion. If the students are collecting data, the teacher is acting as a facilitator. To record this data on the frequency chart, a tally mark was made 5 times during each 5 minute interval of student activity. The numbers in the frequency chart are the totals for each category for the entire block of time for each observation.

The purpose of the typology is to determine the extent of inquiry-based teaching and learning. As part of the content analysis process, observational data was coded using the seven categories of the typology: students, teacher role, classroom activities, emphasis, instructional strategies, discussion, and lab work. Data is coded in each of these seven categories of the typology using a continuum rating system that ranges from less inquiry based to more inquiry based. Each piece of observational data was coded by examining videotapes, field notes and *VQM* documents in relation to the continuum rating. The continuum rating determined for observational data coded under the student category was based on whether the student was looking for correct answers to complete the assignment verses using evidence to evaluate a hypothesis, reflect on others' ideas and clarify conceptual understanding.

The continuum of the teacher role starts with the teacher as the source of knowledge whose questions elicit factual answers from the students to a facilitator who questions for comprehension. Classroom activities vary from use of algorithms to use of critical thinking skills. The emphasis ranges from abstract to real-world application. Instructional strategies extend from an emphasis on content and individual achievement to a balance of content and process with collaborative relationships. Discussions are coded only when they occur and are analyzed using a continuum from strategies involving closed-ended questions that seek facts to open-ended questions that determine understanding. In addition discussion codes are based on who is doing the most talking and whether evidence is used to support statements that are made.

Observational data is coded into the laboratory category only if lab occurs and it is based on the type of procedure followed by the students as they answer either a single question with one correct answer or use an open-ended procedure with the possibility of many answers. Field notes were used to provide evidence for placement of data on the continuum in each of the seven categories of the typology. Researcher reflections were completed at the end of each observation also were based on the field notes taken by the researcher. The categories for the analysis of the reflection questions were determined by the content of the questions asked by the protocol.

Teacher A

This school district is on block schedule with a block of about 90 minutes that meets every other day. The class participating in this study was an honors physics class of eight seniors, all male but one. The windowless classroom is large and divided into two separate spaces by a lab table that has storage space in the bottom. The front of the room contains student tables that each seat two for lecture and the back of the room has student lab tables. There are two large whiteboards at the front of the room. There are a variety of charts such as a periodic table displayed around the room as well as white boards with student data that appears to be from the *VQM* Activity 1. In the front corner of the room there is a computer for use by the teacher and there is an LCD projector attached to the ceiling. This was used on several occasions during the study. The instructional strategies for Teacher A are described in the information section of the protocol. This information is organized in Data Table 4.19.

Table 4.19 Instructional Strategies: Teacher A

	Predominant Teaching strategies	Lesson introduction	Closure	Modes of instruction	Student activities	Materials used
Act. 1	Followed the worksheet: hands-on activity	Explain activity	Tape stopped while students working	-Whole class discussion -Hands-on activity	-Complete worksheets -Read a hand-out in class -Hands-on activity	-Hand-ou, -Lab equipment -Manipulative -Whiteboard
Act. 2	Followed the worksheet: hands-on activity	-Provide overview -Explain activity -Relate to previous lessons	Tape stopped while students working	-Short Lecture -Whole class discussion -Hands-on activity	-Complete worksheets -Hands-on activity -Put data on whiteboards	-Hand-out -Lab equipment -Manipulative -Whiteboard
Act. 3	Followed the worksheet: minds-on activity	-Provide overview -Relate this to previous lessons -Provide rationale	Teacher summarized the importance of the video	-Whole class discussion -Students solving problems or questions in small groups -Video	-Listen and take notes -complete worksheet -Read a hand-out in class	-Hand-out -Video -Whiteboard
Act. 4	Computer simulation	-Relate this to previous lessons -Provide rationale	Tape stopped while students working	-Short Lecture, -Students working on computer	-Complete worksheets -Work on computer -Watch video	-Hand-out -Video -Computer-based technologies -LCD projector
Act. 5-6	Followed the worksheet: -Minds-on activity -Computer simulation	Other: said read carefully and answer the questions	Students turn in the activities and begin to work on major projects	-Students solving problems or questions in small groups -Working on computers -Other: worked through the worksheets individually	-Complete worksheets - Read a hand-out in class - Work on computer	-Hand-out -Computer-based technologies

Teacher A began each class with an explanation of the day's activity that included an overview, its relationship to previous lessons and the rationale for the activity. The predominant teaching strategies for this teacher include following the worksheet and completing the hands-on and computer activities. The modes of instruction include class discussion, lecture, and small lab groups for the hands-on activities and computer simulations. He followed the order of the activities and used the equipment as outlined by the teacher's guide. Students worked through the activities in groups of 2-3. They read the information on the hand-out, completed the worksheets, hands-on activities and computer simulations and placed data on white boards. Teacher A moved from group to group as the students worked and answered questions as they arose. Students put data on whiteboards for Activity 1 and shared the data with a whole class discussion. At the end of Activity 2 each group of students was assigned a different light source for each group and instructed to draw the spectrum on a whiteboard. This was followed by a whole class discussion to compare and contrast the light sources.

Teacher A enhanced the unit by adding two videos with Activities 3 and 4. Materials used include the hand-outs for each activity, lab equipment, computer-based technology, an LCD projector, and whiteboards. It was impossible to determine the closure at the end of class because many of the tapes were turned off before the bell rang. During one class, students were given a description of what to expect for the next class. On the last day, students turned in their work and used the rest of the block to work on a long-term project that was due the next week. Assessment strategies for all activities included recitation and discussion responses and the data on whiteboards for Activity 1. The size of the groups and the amount of time spent in each configuration are reflected in Data Table 4.20.

Table 4.20 Student Grouping: Teacher A

	Act. 1	**Act. 2 Days 1-2**	**Act. 3**	**Act. 4**	**Act. 5-6**
Whole group	5%	5%	45%	25%	1%
Individuals					95%
Small groups (3-4)		95%	55%		
pairs	95%			75%	4%

Students spent more time in small groups or pairs for Activities 1-4. Teacher A instructed the students to work in groups during Activity 3 but they were very quiet. Activities 5-6 were more individualized because the students did not collaborate as they worked. The higher whole group percentages resulted from the videos that were viewed with these activities. The overall emphasis was determined by the outcomes of the activity, the types of questions used by the instructor and the amount of time spent in lecture, discussion, and lab. Major emphasis was placed on understanding science concepts, following a written procedure and collecting data. Minor emphasis was placed on learning facts, assessing prior knowledge, learning real-world applications, engaging in thinking skills and developing skill in working collaboratively.

Additional information about the teaching strategies was determined using the frequency chart that plots student activity. The results of these data can be found in Data Table 4.21.

Table 4.20 Frequency of Student Activity: Teacher A

Code	Students' specific behavior	Act. 1	Act. 2	Act. 3	Act. 4	Act. 5-6
SS1	Listening to the instructor talk	3	5	28	25	0
SS2	Listening to a student talk	1	0	0	0	0
SS3	Interacting directly with instructor (responding to or Asking questions of the instructor	14	10	12	12	7
SS4	Discussing relevant class material with each other (Data/results, concepts, debating, asking questions)	6	2	12	4	5
SS5	Reading class materials (handouts, notes papers, etc.)	4	0	5	2	6
SS6	Engaging in minds-on activity (solving problems, reflecting on work, drawing conclusions)	1	0	0	0	0
SS7	Transferring info to written form (filling out worksheets, Taking notes, taking tests)	10	13	10	11	20
SS8	Replicating science (following explicit procedures, verifying known phenomena, collecting data, hands-on activity)	23	12	3	0	0
SS9	Practicing science (formulating questions to investigate, designing ways to answer questions)	0	0	0	0	0
SS10	Working on computer for work processing	0	0	0	0	0
SS11	Working on computer for simulations	0	0	0	20	11
SS12	Undetermined (i.e. staring)	0	1	3	4	1
SS13	disengaged	1	2	1	5	1
SS14	Other:					

The large number of tallies in the SS1 category during Activities 3 and 4 were produced by the videos that the students viewed during those activities. The low numbers in this category during all other activities indicate that Teacher A did not lecture frequently. The researcher did not observe any student presentations of data which accounts for the low number of tallies for SS2. Category SS3 shows a frequent interaction between the students and the instructor as the activities were completed. The tallies for category SS4 demonstrate that the students also were discussing the subject matter within their groups as they worked. Students talking between groups are reported in these data as well. Categories SS6, SS7 and SS8 are an indication that as the students followed the activities, they had to read and follow directions, collect and interpret data. The teacher moved from group to group as a facilitator during the activities. Category SS9 includes low numbers because *VQM* is not designed for student hypotheses. Students did not use the computers for word processing but tallies indicate that Activities 4 and 5 includes the computer for simulations. There were times when student behavior was undetermined or disengaged. This sometimes occurred during transitions between class discussion and lab activities, while equipment was retrieved, or as computers where logging on. In addition, field notes explain that the camera is at the back of the room and it is sometimes difficult to see what the students are doing.

When the data for all activities combined were placed on the typology scale, they covered the continuum. Each section of the typology scale was cross analyzed for each activity. The numbers on the scale represent the activity number. Data can be found in Data Table 4.22.

Table 4.21 Typology of Instructional Strategies: Teacher A

Less inquiry-based:	**More inquiry-based**
Students	---5-------------3----------4----2------------1------------
Teacher role	-------------------------3---2-------4---5--------1------
Classroom activities	----------5---3-----------------------4----------2--1---
Emphasis	---------------------2---4----3---------------------5--1--
Instructional strategies	-------------------5--------------3-4----------------1-2—
For discussion	--4----------------------------2-----------------------1------
For Laboratory	-------------5--------------------------------2--1-------4--

In the student category, Activity 1 requires students to use evidence to answer questions and information from other groups to interpret data. In Activity 2, evidence was also used; however, the discussion was teacher-led and there were times when the students did not do much talking. Students worked alone on Activity 3; however, the activity helps students build a conceptual model which is abstract. Activity 4 uses a computer simulation as evidence for answers; but, this group of students did very little talking as they worked. Activities 5 and 6 are combined on the table as a 5. Students worked quietly and did not ask the instructor many questions.

The role of the teacher in Activity 1 was that of a facilitator as the students worked through the lab in groups. The discussion on the second day of Activity 2 included more close-ended questions than open-ended questions; but, once the hands-on activity began, the teacher acted as a facilitator. This role continued with Activity 3. The video shown on that day places the teacher on the middle of the spectrum. During Activities 4, 5, and 6 the teacher was a facilitator. Students did not ask many questions during Activities 5 and 6.

When considering classroom activities, Activities 1 and 2 are inquiry-based. The data collected in these activities are used to look for patterns and compare and contrast the characteristics of the light sources. There are specific answers developed in Activity 3. The video describes real-world applications for the information from the unit so it is closer to the middle of the continuum. The computer simulation in Activity 4 follows a process to produce energy diagrams; but, different groups finish with different diagrams so Activity 4 was placed in the middle of the continuum. Activities 5 and 6 produce specific answers as students explain how this information is applied in real life and so they are less inquiry-based.

The rating for emphasis looks different when compared to classroom activities. During the discussion for Activity 1, Teacher A pointed out that LEDs are cool light which is why they can be embedded in plastic as found on a television. The information uses “real-life” light sources and ends with an application question. Gas lamps and spectra are not used by students on a daily basis; however, the last question that determines the gas in fluorescent bulbs is a practical application. Activity 3 is very abstract; but, the video showed real-world connections. The spectra in Activity 4 are abstract for the students; but, the video had real-life applications. Activities 5 and 6 emphasize that scientists use this information in practical ways.

For instructional strategies, all of the *VQM* activities are written with a balance of content and process with the intent of fostering collaborative work or class discussion. Activities 3 and 4 were coded along the middle of the continuum because class discussion did not occur and videos were shown with both activities. The students worked alone on Activities 5 and 6 so these were rated as less inquiry-based.

The discussion during Activity 1 was about 10 minutes long and included a variety of open-ended questions to compare and contrast the light sources. Activity 2 required two days to complete. Though there was no discussion on the first day; the second day started with a review discussion of close-ended question and ended with an open-ended discussion to compare data. Activity 4 began with a five minute review that was prompted by predominantly close-ended questions. Discussions did not occur during Activities 3, 5 and 6 so they are not found on the continuum.

Lab activities were conducted in Activities 1, 2, 4, and 5. In Activity 1, the procedure is described in the handout; but, the students must use the data to look for patterns. They also compare and contrast different light sources. The activity ends with an open-ended application question. The same is true for Activity 2; however, it ends with an application question that has only one answer. Activity 3 is not a lab exercise so it was not coded using this continuum. The procedure for the computer simulation in Activity 4 results in an energy diagram that can explain the spectral lines for hydrogen; however, the energy diagrams may be different for each group. The computer simulation in Activity 5 directs all groups to the same answer so the activity is on the less inquiry-based side of the continuum. Activity 6 is not a lab exercise and therefore was not coded using the continuum.

The last portion of the classroom observation protocol is a series of questions for the researcher to answer by reflection and interpretation based on the field notes. These reflections and interpretations were coded into categories according to the questions that were asked: effective implementation, things not observed, alternative teaching strategies, student attitudes, instances of inequity, non-verbal behavior of the students, and concerns of the researcher. Researcher reflections and interpretations are presented by category in Data Table 4.23.

Table 4.22 Reflections: Teacher A

	Effective Implementation	**Things Not observed**	**Alternative methods**	**Student attitudes**	**Instances of inequity**	**Non-verbal behavior**	**Concerns**
Act. 1	-Students on task -Teacher is facilitator -Data showed expected eV values	Didn't finish - evidence of understanding not observed	None needed	Students on task while collecting data but less so during discussion	None observed	None observed	Not at this point

Act. 2	On day 1: -Students on task -Teacher is facilitator -Data showed expected spectra On day 2: -Students on task -Teacher is facilitator -First discussion checks understanding -End discussion compares and contrasts data	On day 1, Didn't finish - evidence of understanding not observed On day 2, -Student interest not observed -Beginning review was more lecture than discussion	On day 1; The class needs more group discussion of data On day 2; Students need to present data verbally instead of just making whiteboards	On day 1; -Some students didn't talk to teacher at all -Others asked lots of questions. -Some were disengaged during data collection On day 2; students were on task but less so during discussion	On day 1; Group not within the camera view did not seem to ask many questions. On day 2; None observed	Day 1; Playing such as "Morse Code" with the circuit board. Day 2; Looking into camera, some talking not associated with content	Day 1; Student(s) who believe that the teacher is not teaching. Day 2; Not at this point
Act. 3	-Students on task but worked quietly -Short lecture-discussion to check understanding -Video	-Students described electron energies in interview. -Evidence of understanding not observed for all students	More discussion about activity 3 and the video	Students say "Teacher doesn't teach".	None observed	Slouching and heads down during the video	Very little discussion so evidence of understanding not observed
Act. 4	-Students not always on task -Teacher is facilitator -Short close-ended discussion to start class	-No discussion so evidence of understanding not observed	More discussion of simulation results or whiteboard the diagrams	-Stayed on task but not enthusiastic -Did not pay attention to video	None observed	Most did not really pay attention to the video	-Students did not seem to enjoy the computer simulation -Very little discussion so evidence of understanding not observed
Act. 5-6	-Students on task but very quiet -Teacher interaction is minimal	-Student collaboration was not observed even though instructions were to work in pairs	More class discussion to check for understanding at the end of each activity	Stayed on task but not enthusiastic	None observed	Arms crossed and doing nothing	Very little discussion so evidence of understanding not observed

The category for effective implementation requires the researcher to determine if the teaching strategies advocated by the *VQM* program are effective. Based on researcher reflections and interpretations, Activities 1 and 2 were effective. The students stayed on task and their data showed "correct" eV values and spectral diagrams. Although the students worked on Activity 3 in pairs, the room was very quiet and a whole class discussion did not occur so the activity was not rated as effective. The students did not stay on task while doing Activity 4 which made it less effective. Activities 5 and 6 did not include a class discussion but the students did stay on task which is effective.

There were many instances when the students were not finished with an activity at the end of the block. When this occurred in Activities 1 and 2, there was little evidence of student understanding. During Activities 3 and 4, a discussion did not occur so student understanding of energy diagrams was not apparent and the differences in the energy diagrams produced by different groups were not observed. Based on the instructions for previous activities, the researcher expected the students to work in pairs on Activities 5 and 6, but the students did not talk to one another as they continued working individually.

Alternative strategies that the instructor might have used for most of the activities include more class discussion of results and verbal presentations of student data. This would allow more comparisons and the opportunity to check for student understanding. An example would be during Activity 2 when the teacher tried to save time by instructing the students to compared results among themselves instead of having a whole class discussion. That being said, the students were much more interested when they were collecting data and did not contribute during the discussions that occurred. The student attitudes could be described as participating but lacking enthusiasm. During the interview, students revealed that they enrolled in honors physics only because it's a "weighted" class. Equity was not an issue for this class because all 8 students were equitably involved. Notable nonverbal behavior included a student doing Morse code with the LED on the circuit board and slouching or heads down on the desks when the videos were playing. A major concern is that the students perceived that they were "teaching" themselves and that the teacher was not helpful. During the video tape of Activity 2 a student looked directly into the camera and said "This is what happens when the teacher doesn't teach." The observation of Activity 3 does not show the minds-on process that should occur. Students did not seem interested in the unit; however, this unit occurred during the last part of the school year. There was no way to determine if the students understood any of the information because of the lack of discussion.

Teacher B

This district is on a traditional schedule in which an hour is about 50 minutes long. Two sections of physics participated in the observational study. The smaller class with 11 students met during 2nd hour and the larger class with 18 students met during 5th hour. The classroom is large. Lab stations are along two walls of the room with tables for two students each in the center of the room. One of the lab stations is used as a teacher "desk" and has a podium next to it. The podium holds the computer that is equipped with a video camera. There are posters on the walls that include student work. There is a demonstration table at the front of the room. Every student has a laptop computer supplied by the school district. The instructional strategies for Teacher B are described in the information section of the protocol. This information can be found in Data Table 4.24.

Table 4.23 Instructional Strategies: Teacher B

	Predominant Teaching strategies	**Lesson introduction**	**Closure**	**Modes of instruction**	**Student activities**	**Materials used**
Act. 1	No observation on tape	No observation on tape	No observation on tape	No observation on tape	No observation on tape	No observation on tape
Act. 2 2nd hr	-Teacher directed questions -Students write answers	-Provide overview -Relate to previous lessons -Assess prior knowledge	Work on homework – summarize the data from the day's activity	-Whole class discussion -Hands-on activity	-Complete worksheets -Hands-on activity	-Hand-out - Lab equipment -Manipulative -Chalkboard
Act. 2 5th hr	-Students use spectroscopes. -Teacher asked questions while students answered on lab report	-Assess prior knowledge	Tape stopped while students working	-Teacher demo -Whole class discussion -Hands-on activity	-Complete worksheets -Hands-on activity	-Hand-out -Lab equipment -Manipulative -Chalkboard
Act. 3 2nd hr	Followed the worksheet: -Minds-on activity -Computer simulation as Act. 4 begins	-Explain activity, -Relate to previous lessons -Assess prior knowledge	Tape stopped while students working	-Students working on computer -Other: work through a worksheet	-Complete worksheets -Hands-on activity	-Hand-out -Computer based technology -Chalkboard
Act 3. 5th hr	Followed the worksheet: -Minds-on activity	-Provides rationale -Assess prior knowledge -Other: read activity	Finish Act. 3 then work on other projects	-Whole class discussion -Other: work through a worksheet	-Complete worksheets -Read hand-out	-Hand-out -Chalkboard

Act. 4 5th hr	Computer simulation	-Other: unknown	Before bell rang, teacher told students to put up computers then turned off camera	-Students working on computer	-Complete worksheets -Work on computer	-Hand-out -Video -Computer-based technologies

A video tape of Activity 1 was not made so this activity is not included in the data. Teacher B began each class with an explanation of the day's activity that included an overview, its relationship to previous lessons and/or the rationale for the activity. There were times when the taping began after the students were already working on the day's activities. The predominant teaching strategies for this teacher include teacher-directed questioning, following the worksheet and completing the hands-on and computer activities. The modes of instruction include class discussion and small lab groups for the hands-on activities and computer simulations. She followed the order of the activities and used the equipment as outlined by the teacher's guide.

During Activity 2, Teacher B used whole class teacher-lead discussions and/or reading the questions for students to answer. If the students did not answer, she provided the answers. At other times, students worked through the activities in groups of two or three. They read the information on the hand-out, completed the worksheets, worked on hands-on activities or computer simulations and reported data to the teacher as she recorded it on the chalkboard. Teacher B moved from group to group as the students worked and answered questions as they arose. Materials used include the hand-outs for each activity, lab equipment, manipulatives, computer based technology, and chalkboards. Assessment strategies for all activities included recitation and discussion responses. The size of the groups and the amount of time spent in each configuration are noted in Data Table 4.25.

Table 4.24 Student Grouping: Teacher B

	Act. 1	**Act. 2 Both hrs.**	**Act. 3 Both hrs.**	**Act. 4**
Whole group		75%	10%	
Individuals			90%	
Small groups (3-4)		25% (group 2-3)		100%
pairs				

Activity 2 was done as a whole class until the circuit boards were needed for the LEDs. Activity 3 was completed individually while small groups were in place for Activity 4. The overall emphasis was determined by the outcomes of the activity, the types of questions used by the instructor and the amount of time spent in lecture, discussion, and lab. Major emphasis was placed on learning facts or definitions, understanding science concepts, and collecting data. Minor emphasis was placed on assessing prior knowledge, following a written procedure, interpreting data, and developing skill in working collaboratively.

Additional information about the teaching strategies was determined by use of a frequency chart that plots student activity. The results of these data can be found in Data Table 4.26.

Table 4.25 Student Activity: Teacher B

Code	Students' specific behavior	Act. 2 2nd hr	Act. 2 5th hr	Act 3. 2nd hr	Act. 3 5th hr	Act. 4 5th hr
SS1	Listening to the instructor talk	4	3	6	5	0
SS2	Listening to a student talk	0	0	0	0	0
SS3	Interacting directly with instructor (responding to or Asking questions of the instructor	15	16	11	4	8
SS4	Discussing relevant class material with each other (Data/results, concepts, debating, asking questions)	0	2	3	4	4
SS5	Reading class materials (handouts, notes papers, etc.)	0	0	1	3	0
SS6	Engaging in minds-on activity (solving problems, reflecting on work, drawing conclusions)	0	0	0	0	0
SS7	Transferring info to written form (filling out worksheets, Taking notes, taking tests)	5	6	12	11	4
SS8	Replicating science (following explicit procedures, verifying known phenomena, collecting data, hands-on activity)	7	7	0	0	0
SS9	Practicing science (formulating questions to investigate, designing ways to answer questions)	0	0	0	0	0
SS10	Working on computer for work processing	0	0	0	0	0
SS11	Working on computer for simulations	0	0	6	0	19
SS12	Undetermined (i.e. staring)	2	0	0	7	0
SS13	disengaged	6	6	5	3	0
SS14	Other:					

The number of tallies in the SS1 category was produced by the introductions to the activities. The low numbers in category SS1 indicate that Teacher B did not lecture frequently.

The researcher did not observe any student presentations of data which accounts for the low number of tallies for category SS2. Category SS3 shows a frequent interaction between the students and the instructor as the activities were completed. The tallies for category SS4 demonstrate that the students sometimes discussed within their groups as they worked. Students talking between groups also are represented in this data. Category SS6 has no tallies because the camera was in the back of the room and the researcher could not hear the students as they discussed the activities. Categories SS7 and SS8 are an indication that as the students carried out these activities, they had to read and follow directions, in order to collect and interpret data. The teacher moved from group to group serving as a facilitator for their activities. Category SS9 has no tallies because *VQM* is not designed for student hypotheses. Students did not use the computers for word processing; but, tallies indicate that Activity 4 includes the computer for simulations. There were times when student behavior was undetermined or disengaged. While this sometimes occurred during transitions between class discussion and lab activities, there were instances when students were surfing the web instead of working on the activity. In addition, field notes explain that the camera is at the back of the room and it is sometimes difficult to see what the students are doing.

When the data for the combined activities were placed on the typology, they covered the continuum from one end to the other. Each section of the typology is cross analyzed for each activity. The numbers on the scale represent the activity number as these data can be found in Data Table 4.27.

Table 4.26 Typology of Instructional Strategies: Teacher B

Less inquiry-based:	**More inquiry-based**
Students	-3---2-----------------------------4------------------
Teacher role	-2-3--4-----
Classroom activities	------------3-------------2-----------4--------------
Emphasis	--3-2-4--

Instructional strategies ----------------3----------------4------2--------------

For discussion -----3--2---

For Laboratory ---2--------4---

Activity 1 was not taped so there are no data. In Activity 2, evidence was used to answer the questions; however, the discussion was teacher-led and there were times when the students did not do much talking so the teacher provided the answers to them. Students worked alone on Activity 3; however, the activity helps students build a conceptual model which is abstract. Activity 4 uses a computer simulation as evidence for answers; but, there was no discussion. Teacher B did not complete Activities 5 and 6.

Data coded according to the role of the teacher in Activity 2, indicated that the discussion was used as a source of knowledge. Teacher B led the students through the activity with many fact-based questions. Students were asked to describe data, but inferences were not made. During Activity 3 the students worked individually. Interactions with the teacher resulted with the teacher repeating the students' answers and then elaborating on them. Teacher B was a facilitator during Activity 4 when she moved from group to group and answered questions as they arose.

When considering classroom activities, Activity 2 is inquiry-based because the data collected in the activity are used to look for patterns and compare and contrast the characteristics of the light sources. However, the teacher gave many of the answers to the students so this activity was coded along the middle of the continuum. There are specific answers developed in Activity 3, so it is less inquiry-based. The computer simulation in Activity 4 follows a process to produce energy diagrams; but, groups finish with different diagrams so it is coded in the middle of the continuum.

The rating for emphasis looks different when compared to classroom activities. Gas lamps and spectra are not used by students on a daily basis; however, the last question that determines the gas in fluorescent bulbs is a practical application. Activity 3 is very abstract. The spectra in Activity 4 are abstract for the students as well. For instructional strategies, all of the *VQM* activities are written with a balance of content and process with the intent of collaborative work or class discussion. During Activity 2, students worked in groups while using the spectroscopes, but discussion was minimal. Activities 3 and 4 were coded along the middle of the continuum because class discussion did not occur.

Observational data coded using the continuum for discussion indicates Activities 2 and 3 were less inquiry-based because the discussions were teacher-driven. The questions were closed and fact-seeking and the teacher provided the reasoning as well. Activity 4 is not present because there was no discussion with this activity.

Lab activities were conducted in Activities 2 and 4. In Activity 2, the procedure is described in the handout; but, the students must use the data to compare and contrast different light sources. The activity ends with an application question that has only one answer. Activity 3 is not a lab exercise, so it was not coded using this continuum. The procedure for the computer simulation in Activity 4 results in an energy diagram that can explain the spectral lines for hydrogen; however, the energy diagrams may be different for each group.

The last portion of the classroom observation protocol is a series of questions for the researcher's reflection and interpretation. The researcher's field notes were used to answer the questions. Researcher reflections and interpretations were coded into categories based on the questions that were asked: effective implementation, things not observed, alternative teaching strategies, student attitudes, instances of inequity, non-verbal behavior of the students, and concerns of the researcher. Researcher reflections and interpretations are presented by category in Data Table 4.28.

Table 4.27 Reflections: Teacher B

	Effective Implementation	**Things Not observed**	**Alternative methods**	**Student attitudes**	**Instances of inequity**	**Non-verbal behavior**	**Concerns**
Act. 1	No observation	No observation	No observation	No observation	No observation	No observation	No observation
Act. 2 2nd hr	-During the teacher led discussion the students waited for the teacher to give the answer to fill in worksheet. -Each group looked at 1 or 2 LEDs then the data was	Open-ended discussion - even the compare and contrast questions were lead by the instructor.	-Have each group look at all the light sources, then compare data with other groups during a class discussion	-The students were not engaged. -The teacher asked many questions that students did not answer.	-One group answered most of the questions. -The two females asked for more help. -One male and one female were not engaged	-Two students put their heads on the desk. -Several students had other programs going on their computers.	–Activity was not complete in small groups -Close-ended discussion

	combined on the board				at all.		
Act. 2 5th hr	-Activities were teacher directed except when actually taking data. -Proximity was good.	-Small group work for observation of all light sources	-Have each group look at all the light sources, then compare data with other groups during a class discussion	-Stayed on task but not enthusiastic	-The teacher spent most of the time on one side of the classroom.	-Laptops used but not required. -A couple of students built a tower with the spectroscopes	–Activity was not complete in small groups -Close-ended discussion.
Act. 3 2nd hr	-Activity 3 had little discussion. Students did not ask many questions. - The teacher explained the simulation.	-No discussion so evidence of understanding not observed	-More discussion about activity 3.	-Most stayed on task. -Off-task internet use occurred.	-The teacher spent most time one side of the room -That side also asked more questions.	-Unapproved internet use during activity 3. -Another student was reminded several times to focus on activity 4.	Very little discussion so evidence of understanding not observed
Act. 3 5th hr	-Students were not focused. -Questions were for knowledge rather than conceptual.	-No focus for 10 minutes were disengaged. -No discussion so evidence of understanding not observed	-More discussion about activity 3 -There was time to begin activity 4.	-Students off task. - There was constant chatter and singing.	-Not observed	-There were students wandering around the room.	-Poor use of class time. -Very little discussion so evidence of understanding not observed
Act. 4 2nd hr	-Students on task -Teacher is facilitator -Students did not ask many questions.	-No discussion so evidence of understanding not observed	-End class with a discussion of the results	-Students on task	-Not observed	-Not observed	-Very little discussion so evidence of understanding not observed
Act. 4 5th hr	-Students on task -Teacher is facilitator -Students did not ask many questions.	-No discussion so evidence of understanding not observed. -They did not finish.	-End class with a discussion of the results	-Students on task	-Not observed	-A male kept putting his head on a female’s shoulder.	-Very little discussion so evidence of understanding not observed

The category for effective implementation requires the researcher to determine if the teaching strategies advocated by the *VQM* program are effective. Based on these reflections and interpretations, Activity 2 was not effective because Teacher B did not really use the teaching strategies advocated by the *VQM* program during this activity. The class discussion and the observations of a large incandescent lamp and a green lamp were lead by the teacher as the students wrote the answers on their papers. As a result, many students waited for the answers to be given to them by the teacher. When students began to look at the LEDs in the circuit boards, they were more independent and Teacher B moved from group to group as a facilitator would. Students in the 2^{nd} hour worked on Activity 3 very quietly and a whole class discussion did not occur so the activity was not rated as effective. While the 5^{th} hour students did have a short discussion, it was more knowledge-based than conceptual and the students were not as focused as the 2^{nd} hour group. The students did stay on task while doing Activity 4 which accounts for its being rated as more effective.

There were many instances when the students were not finished with an activity at the end of the hour. When this occurred, there was little evidence of student understanding. The students were not given the opportunity to work through Activity 2 by themselves. Teacher B read through most of the activity with the students and answered the questions, including the compare and contrast questions. During Activity 3, 2^{nd} hour did not have a discussion and 5^{th} hour did not stay focused; making it difficult to determine student understanding of the energy diagram concept. A discussion did not occur with Activity 4 either; so student understanding of the differences in the energy diagrams produced by different groups was not observed.

Alternative strategies that the instructor might have used for the activities include more class discussion of results with less teacher elaboration. Teacher B might have allowed the students to work through Activity 2 by themselves, gather the data from all colors of LEDs and then have a whole class discussion to compare the data. This would provide the opportunity to check for student understanding. Teacher B could have ended Activities 3 and 4 with a short class discussion to review and check for understanding. The student attitudes could be described as "participating but lacking enthusiasm". During group activities there was constant chatter and a couple of students were playing on the computer as well.

Equity should not be an issue for 2^{nd} hour because there were only 11 students enrolled. However, it seemed as though one group of three males answered most of the questions and the group of two females asked more questions. During 5^{th} hour, Teacher B seemed to "favor" one side of the classroom during Activities 2 and 3. All groups participated equitably during Activity 4. Notable nonverbal behavior included students with their laptops open and running other programs during Activities 2 and 3. A group of students built a "tower" of spectroscopes during Activity 2. Students seemed to be wandering around the room during Activity 3. A major concern is that Activity 2 was not done as an inquiry-based lab. There was poor use of class time on Activity 3 during 5th hour. The students are all seniors and it is the last week of school so "senioritis" had definitely affected the focus of the class. There was no way to determine if the students understood any of the information because of the lack of discussion.

Teacher C

This district is on a traditional schedule where an hour is about 50 minutes long. One section of physics comprised of only two female students participated in the observational study. The classroom is not large and it is a converted greenhouse with lots of windows and natural light. There are tables rather than desks and no lab stations. There are cabinets along one wall and a whiteboard on another wall. There is a roller coaster set up on one of the tables and a computer on another table. The classroom is used for math classes as well. The instructional strategies for Teacher C are described in the information section of the protocol. This information can be found in Data Table 4.29.

Table 4.28 Instructional Information: Teacher C

	Predominant Teaching strategies	**Lesson introduction**	**Closure**	**Modes of instruction**	**Student activities**	**Materials used**
Act. 1	No observation on tape	No observation on tape	No observation on tape	No observation on tape	No observation on tape	No observation on tape
Act. 2	-Teacher working with students to collect lab data -Hands-on	-Explain activity -Other: set up lab in another room	-We will finish next time - Assigns activity 3 as homework	-Discussion -Students solving questions (teacher is learning with the students) -Hands-on activity	-complete worksheet -Read hand-out -Hands-on activity	-Worksheet -Lab equipment -Manipulative -Other: improvised a black paper "tent"
Act. 3	Read and answer the worksheet: minds-on activity	-Explain activity	Teacher describes what will happen for the next couple of classes	-Class discussion, -Other: reading	-Complete worksheets, -Read hand-out	-Hand-out -Manipulative
Act. 4	-Computer simulation -Teacher/student discussion	Explain activity	We'll continue this tomorrow	-Teacher Demo -Class discussion, -Working on computer	-Complete worksheets -Work on computer	-Hand-out -Computer-based technologies
Act. 5	-Read and answer	Explain	Took post-test	-Students	-Complete	-Hand-out

	questions -Computer simulation	activity	after completing	solving questions -Working on computers	worksheets -Work on computer	-Computer-based technologies

A video tape of Activity 1 was not made so this activity is not included in the data. Teacher C began each class with an explanation of the day's activity. There were times when the taping began after the students were already working on the day's activities. The predominant teaching strategies for this teacher include following the worksheet and completing the hands-on and computer activities. The modes of instruction include class discussion, students solving questions, and a lab group for the hands-on activities and computer simulations. Teacher C followed the order of the activities and used the equipment as outlined by the teacher's guide. Student activities included reading the hand-out (sometimes aloud), completing the worksheet, working through on hands-on activities and the computer simulations. Teacher C worked with the students as a group member during Activity 2. Materials used include the hand-outs for each activity, lab equipment, manipulatives, computer based technology, and an improvised black paper "tent" in which to take data on the circuit board data. Assessment strategies for all activities included recitation and discussion responses. The size of the groups and the amount of time spent in each configuration are shown in Data Table 4.30.

Table 4.29 Student Grouping: Teacher C

	Act. 1	**Act. 2 Both hrs.**	**Act. 3**	**Act. 4-5**
Whole group				
Individuals				
Small groups (3-4)				
Pairs		100%	100%	100%

All activities were done by the two students working as a pair. The overall emphasis was determined by the outcomes of the activity, the types of questions used by the instructor and the amount of time spent in lecture, discussion, and lab. Major emphasis was placed on understanding science concepts, following a written procedure, and interpreting data. Minor emphasis was placed on learning facts or definitions, assessing prior knowledge, learning real-world applications, collecting data, and developing skill in working collaboratively.

Additional information about the teaching strategies was determined using the frequency chart that plots student activity. The results from these data can be found in Data Table 4.31.

Table 4.30 Student Activity: Teacher C

Code	Students' specific behavior	Act. 2 Day 1	Act. 2 Day 2	Act 3.	Act. 4/5
SS1	Listening to the instructor talk	1	0	0	1
SS2	Listening to a student talk	0	0	0	0
SS3	Interacting directly with instructor (responding to or asking questions of the instructor	7	9	9	18
SS4	Discussing relevant class material with each other (Data/results, concepts, debating, asking questions)	0	0	1	0
SS5	Reading class materials (handouts, notes papers, etc.)	5	1	8	11
SS6	Engaging in minds-on activity (solving problems, reflecting On work, drawing conclusions)	1	0	1	0
SS7	Transferring info to written form (filling out worksheets, Taking notes, taking tests)	4	1	7	6
SS8	Replicating science (following explicit procedures, verifying known phenomena, collecting data, hands-on activity)	7	16	10	0
SS9	Practicing science (formulating questions to investigate, designing ways to answer questions)	0	0	0	0
SS10	Working on computer for work processing	0	0	0	0
SS11	Working on computer for simulations	0	0	0	8
SS12	Undetermined (i.e. staring)	0	0	0	0
SS13	disengaged	0	0	1	1
SS14	Other:				

The tallies in the SS1 category during Activities 2 and 4 were produced by the introductions to the activities. The low numbers in this category indicate that Teacher B did not lecture frequently. The researcher did not observe any student presentations of data which accounts for the low number of tallies for SS2. Category SS3 shows a frequent interaction between the students and the instructor as the activities were completed. The tallies for categories SS4, SS5, and SS6 demonstrate that the students sometimes discussed within their groups as they worked. Categories SS7 and SS8 are an indication that as the students followed the activities, they had to read and follow directions, collect and interpret data. The teacher acted as a facilitator for their activities. Category SS9 has no tallies because *VQM* is not designed for student hypotheses. Students did not use the computers for word processing but tallies indicate that Activities 4 and 5 include the computer for simulations. There were times when student behavior was disengaged, for example when the teacher had problems getting the "Spectroscopy Lab Suite" program to work properly on her laptop computer.

When the combined data for all activities were placed on the typology, they covered the continuum from one end to the other. Each section of the typology is cross analyzed for each activity. The numbers on the scale represent the activity number. Data can be found in Data Table 4.32.

Table 4.31 Typology of Instructional Strategies: Teacher C

Less inquiry-based:	**More inquiry-based**
Students	-------5-----3--4---------------------------------2------
Teacher role	----------5--3--4---------------------------2-----------
Classroom activities	------------5--3--------------------------4-2----------
Emphasis	-----3---4---------------------2-----------5--------------
Instructional strategies	---------------------------------------5--3--4--2---------
For discussion	-----5--3-----------------4----------------2-----------------
For Laboratory	-----------5----------------------------4-----2-----------

Activity 1 was not taped so there is no data. In Activity 2, students used the evidence to answer the questions. The discussion included the relationship of color to eye sight. In addition, the students asked to stay under the "tent" to try something that was not part of the lab. Students worked alone on Activity 3 and seemed to get the "correct" answers; however; the activity helped students build a conceptual model which is abstract. Activity 4 uses a computer simulation as evidence for answers; but, the teacher frequently used the teacher guide to confirm the answers. Students worked with the teacher on Activity 5. They read the activity aloud and on several occasions Teacher C re-worded the questions for better understanding. She used the teacher guide to confirm answers for this activity. Teacher C did not complete Activity 6.

The role of the teacher for Activity 2 was that of a group member as she worked through the activity with the students and discussed the data and its interpretation. However, she used the teacher guide to confirm answers which is equivalent to the teacher acting as a source of knowledge. This role continued with Activity 3 which is not a hands-on activity. During Activities 4 and 5 the teacher did ask some leading questions. She allowed the students to work through the computer simulations without her participation.

When considering classroom activities, Activity 2 is inquiry-based because the data collected in the activity are used to look for patterns and compare and contrast the characteristics of the light sources. Students also were allowed to try an additional test with the circuit boards. There are specific answers developed in Activity 3 so it is less inquiry-based. The computer simulation in Activity 4 follows a process to produce energy diagrams. In a classroom with multiple groups, different diagrams will be produced; but, with only one group, this could not be observed although it was briefly discussed. This placed Activity 4 on the less inquiry-based side of the continuum. Activities 5 produces specific answers as it helps students understand how this information is applied in real life so it is less inquiry-based.

The rating for emphasis looks different when compared to classroom activities. Gas lamps and spectra are not used by students on a daily basis; however, the last question that determines the gas in fluorescent bulbs is a practical application. Activity 3 is very abstract. The spectra in Activity 4 are abstract for the students as well. Activity 5 emphasizes that scientists use this information in practical ways. For instructional strategies, all of the *VQM* activities are written with a balance of content and process with the intent of collaborative work or class discussion. All of the activities are on the more inquiry-based side of the continuum because the students worked together on all of the activities.

The continuum for discussion shows Activity 2 on the more inquiry-based side of the scale because the data were discussed. The questions for Activity 3 were closed and fact-seeking and the teacher provided the reasoning as well; so it was codes on the less inquiry-based side of the continuum. Activity 4 is coded in the middle of the continuum because the questions asked by the teacher were a mixture of open-ended and close-ended questions. Because Teacher C relied on the teacher guide for fact finding on Activity 5, it is place on the less inquiry-based side of the continuum.

Lab activities were conducted in Activities 2, 4, and 5. In Activity 2, the procedure is described in the handout but the students must use the data to compare and contrast different light sources. The activity ends with an application question that has only one answer. Activity

3 is not a lab exercise so it was not coded using this continuum. The results from Activity 4 are different for different groups but with only one group this was not possible to experience. Activity 5 has very specific answers so the activity is on the less inquiry-based side of the continuum.

The last portion of the classroom observation protocol is a series of questions for the researcher's reflection and interpretation. The researcher's field notes were used to answer the questions. Researcher reflections and interpretations were coded into categories based on the questions that are asked: effective implementation, things not observed, alternative teaching strategies, student attitudes, instances of inequity, non-verbal behavior of the students, and concerns of the researcher. Researcher reflections and interpretations are presented by category in Data Table 4.33.

Table 4.32 Reflections: Teacher C

	Effective Implementation	**Things Not observed**	**Alternative methods**	**Student attitudes**	**Instances of inequity**	**Non-verbal behavior**	**Concerns**
Act. 1	No observation	No observation	No observation	No observation	No observation	No observation	No observation
Act. 2	-Students on task -Teacher is group member -Data showed expected spectra	Didn't finish - evidence of understanding not observed.	Observe brightness of the spectral lines before going back to class.	Students on task while collecting data but less so while answering questions.	None observed	None observed	-The teacher is not comfortable with the content. -It went slowly as they read the worksheet.
Act. 3	-Students on task -Teacher interacts occasionally	Students did not do their homework	None	Not as enthusiastic about activity 3.	One student did most of the reading	One student did not follow along while reading aloud.	This activity could have been done as homework.
Act. 4	-Students on task -Teacher is facilitator but checks teacher's guide	Teacher looking up answers - evidence of understanding not observed	Let students work alone more often.	Students on task	None observed	None observed	Teacher frequently "gave" the answers so they waited for that to happen.
Act. 5-6	-Students on task -Teacher is facilitator but checks teacher's guide	Teacher looking up answers - evidence of understanding not observed	Let students work alone more often.	They were enthusiastic when they got the energy diagram done.	None observed	None observed	The teacher continues to look up the answers and confirm them.

The category for effective implementation requires the researcher to determine if the teaching strategies advocated by the *VQM* program are effective. Based on researcher reflections and interpretations, all activities were effective. With only 2 students, all activities were completed as a small group with the teacher participating in the discussions as part of the group. The use of the teacher guide was not advocated by the *VQM* program; however, Teacher C was not comfortable with the content at this point.

There were many instances when the students were not finished with an activity at the end of the hour. When this occurred there was little evidence of student understanding. The students did not do Activity 3 as homework as it was assigned. The understanding of the connection between photons released and electrons changing energy levels was difficult to determine.

Alternative strategies that the instructor might have used for the activities include allowing the students to work alone more often and then discuss to check for understanding. Activity 2 would have gone more smoothly and in less time if Teacher C had been prepared to ask the students about the brightness of the spectral lines before returning to the classroom. It would have been time effective to re-assign Activity 3 as homework, but the information from this activity is needed to understand Activity 4.

The student attitudes could be described as positive. They seemed to enjoy looking as the spectra and the hands-on activities. They were less interested in Activity 3 and seemed bored while reading aloud. There was genuine excitement on Activity 5 when they completed the energy diagram. Equity is not an issue with only two students; however, most of the reading was done by one girl. The inattentiveness during the oral reading was the only notable nonverbal behavior. A major concern is that the teacher was not comfortable with the content. As a result, the group re-reads several activities to look for answers and the teacher's guide is used as a reference on many occasions. By the time they reached Activity 4, the students had learned that the teacher would give the answers to them eventually so they began to wait for this to occur.

Teacher D

This school district is on block schedule with a block of about 90 minutes that meets every other day. Two sections of physics participated in the study. The smaller class with ten students met during 1st hour and the larger class with 20 students met during 3rd hour. The classroom is large with student desks in the center and lab stations on two of the walls. There are a variety of charts such as a periodic table and student work is displayed around the room. There is a chalkboard at the front of the room and an LCD projector attached to the ceiling. This was used on several occasions during the observational study. Some of the lab equipment set up at the tables is from *VQM* and some is general physics equipment set up to do the same activity. The instructional strategies for Teacher D are described in the information section of the protocol. This information can be found in Data Table 4.34.

Table 4.33 Instructional Information: Teacher D

	Predominant Teaching strategies	**Lesson introduction**	**Closure**	**Modes of instruction**	**Student activities**	**Materials used**
Act. 1	-Lecture -Hands-on	-Provide overview -Relate to previous lessons -Provide rational	-Discussion of results will occur next class -Homework was pre-assigned	-Lecture -Hands-on activity	-Complete worksheets -Read a hand-out in class -Hands-on activity	-Hand-out -Lab equipment, -Manipulative -Computer based technology -LCD projector
Act. 2	-Lecture -Hands-on	-Provide overview -Explain activity -Relate to previous lessons	-Tape stopped while students working	-Lecture -Students solving questions -Hands-on activity	-Listen and take notes -Complete worksheets -Hands-on activity,	-Hand-out -Lab equipment, -Manipulative -Computer based technology -LCD projector -Chalkboard
Act. 3	-Done as homework. -Power-point to review energy diagrams. -Discussed student generated questions	-Do Now Activity – previews Act. 3	-Tape stopped while students working	-Lecture -Whole class discussion	-Listen and take notes	-Hand-out computer based technology -LCD projector
Act. 4	-Demonstration of computer simulation. -Students work on computers	-Computer simulation was demonstrated	-Tape stopped while students working	-Class discussion -Students working on computer	-Complete worksheets -Work on computer,	-Hand-out -Computer-based technologies -LCD projector -Chalkboard
Act. 5	-Lecture: review of energy diagrams - Followed the	-Provide overview -Explain	-Students turn in the activities and	-Lecture -Teacher demo	-Listen and take notes -Complete	-Hand-out -Computer based

	worksheet that is inquiry based.	activity -Relate to previous lessons	either go to the library or visit quietly	-Whole class discussion	worksheets	technology -LCD projector -Chalkboard
Act. 6/7	-Lecture: review of periodic table. - Followed the worksheet that is inquiry based.	-Provide overview -Explain activity -Relate to previous lessons	-Tape stopped while students working	-Whole class discussion -Working on computers -Hands-on activity	-Complete worksheets -Work on computer -Hands-on activity	-Hand-out - Lab equipment -Computer based technology

Teacher D began each class with an explanation of the day's activity that included an overview, its relationship to previous lessons and the rationale for the activity. On several occasions this was embedded in an activity that he called "Do Now". Directives were on a hand-out that the students picked up as they entered the room and they worked on "Do Now" for the first few minutes of the block. The predominant teaching strategies for this teacher include lecture, following the worksheet, and completing the hands-on and computer activities. The modes of instruction include class discussion, lecture, student solving questions, and small lab groups for the hands-on activities and computer simulations. He followed the order of the activities and used the equipment as outlined by the teacher's guide. Students generally worked through the activities in groups of 3-4. Student activities included listening and taking notes, reading the information on the hand-out, completing the worksheets, hands-on activities and computer simulations.

Teacher D moved from group to group as the students worked and answered questions as they arose. He reviewed class data and concepts with whole class discussions during the "Do Now" activity. Materials used include the hand-outs for each activity, lab equipment, computer based technology, an LCD projector, and chalkboard. It was impossible to determine the closure at the end of class because many of the tapes were turned off before the bell rang. During one class, students were given a description of what to expect for the next class. On the last day, students turned in their work and used the rest of the block to work in the library. Assessment strategies for all activities included recitation and discussion responses and observations of group work. The size of the groups and the amount of time spent in each configuration are reflected in Data Table 4.35.

Table 4.34 Student Grouping: Teacher D

	Act. 1	Act. 2 Both hrs.	Act. 3-4	Act. 5-6	Act. 7
Whole group	60%	50%	1 – 50%,	25%	25%
Individuals					
Small groups (3-4)	40% (2-4		3 – 75%	75%	75%
pairs		50%	1 – 50%		

All activities indicate that whole group activities occurred. These are a reflection of the "Do Now" activities and lectures used at the beginning of each block. Small groups and pairs occurred with each activity as well because Teacher D moved into lab activities at the end of each lecture. The overall emphasis was determined by the outcomes of the activity, the types of questions used by the instructor and the amount of time spent in lecture, discussion, and lab. Major emphasis was placed on understanding science concepts, following a written procedure and collecting data. Minor emphasis was placed on learning facts, assessing prior knowledge, learning real-world applications, engaging in thinking skills and developing skill in working collaboratively.

Additional information about the teaching strategies was determined using the frequency chart that plots student activity. The results of this data can be found in Data Table 4.36.

Table 4.35 Student Activity: Teacher D

Code	Students' specific behavior	A1 1st	A1 3rd	A2 1st	A2 3rd	A3/4 1st	A3/4 3rd	A5 1st	A5 3rd	A6/7 1st	A6/7 3rd
SS1	Listening to the instructor talk	23	22	19	27	18	11	11	11	10	12
SS2	Listening to a student talk	0	0	0	1	5	0	0	0	0	0
SS3	Interacting directly with instructor (responding to or asking questions of the instructor	6	7	12	6	5	9	12	7	15	11
SS4	Discussing relevant class material with each other (Data/results, concepts, debating, asking questions	4	5	7	6	1	5	10	9	6	4
SS5	Reading class materials (handouts, notes, papers, etc.)	1	3	2	0	0	0	1	1	3	3
SS6	Engaging in minds-on activity (solving problems, reflecting on work, drawing conclusions)	0	1	4	5	0	0	0	1	1	2
SS7	Transferring info to written form (filling out worksheets, taking notes, taking tests)	14	8	6	5	7	5	11	11	11	13
SS8	Replicating science (following explicit procedures, verifying known phenomena, collecting data, hands-on activity)	20	21	6	7	0	0	0	4	0	0

SS9	Practicing science (formulating questions to investigate, designing ways to answer questions)	0	0	0	0	0	0	0	0	0	0
SS10	Working on computer for work processing	0	0	0	0	0	0	0	0	0	0
SS11	Working on computer for simulations	0	0	0	0	17 Act. 4	21 Act. 4	5	6	7	5
SS12	Undetermined (i.e. staring)	6	5	1	0	3	0	1	0	2	2
SS13	disengaged	1	3	0	0	3	9	7	6	2	4
SS14	Other:	0	0	0	0	0	0	0	0	0	0

The large number of tallies in the SS1 category during all activities was produced by the lectures at the beginning of each block. The researcher observed some student sharing of data on the chalkboard which accounts for the tallies in SS2. Category SS3 shows a frequent interaction between the students and the instructor as the activities were completed. The tallies for SS4 demonstrate that the students also discussed within their groups as they worked. Students talking between groups are in this data as well. Categories SS6, SS7 and SS8 are an indication that as the students followed the activities, they had to read and follow directions, collect and interpret data. The minds-on activity for SS6 was a graph interpretation during the "Do Now" activity. The teacher moved from group to group as a facilitator for their activities. Category SS9 has low tallies because *VQM* is not designed for student hypotheses. Students did not use the computers for word processing but tallies indicate that Activities 4, 5, and 7 includes the computer for simulations. There were times when student behavior was undetermined or disengaged. This sometimes occurred during transitions between class discussion and lab activities, while equipment was retrieved, computers where logging on or students during 3rd block were waiting to go to lunch in the middle of the block. In addition, field notes explain that the camera is at the front of the room and is focused on different areas of the classroom as the block proceeds.

When the data for all activities combined were placed on the typology, they covered the continuum from one end to the other. Each section of the typology is cross analyzed for each activity. The numbers on the scale represent the activity number. Data can be found in Data Table 4.37.

Table 4.36 Typology of Instructional Strategies: Teacher D

Less inquiry-based:	More inquiry-based
Students	---5---3--------7----------1--4---------------------2-------
Teacher role	---3------------6--5--7------------1--2------------4-------
Classroom activities	----------3--------6---7----5------------4----------2--1---
Emphasis	----3--4-----------------2----7---1-------------------6--5----
Instructional strategies	------------------3---------1--2--6-7-5--4--------------—
For discussion	----------all---
For Laboratory	------------------------------5----------------2--1----7---4--

In the student category, Activity 1 prompted students to use evidence to answer questions and gather information from other groups to interpret data; however, the first half of the block was a teacher-centered lecture so it is coded in the middle of the continuum. In Activity 2, evidence was also used. In addition, the "Do Now" activity includes a discussion of the students' interpretation of a graph so it is found on the more inquiry-based end of the continuum. Students worked on Activity 3 as a homework assignment. The activity includes questions with specific answers to build a conceptual model which was checked for understanding during the "Do Now" activity in the following class. Activity 4 is in the middle of the continuum because it uses a computer simulation as evidence for answers; yet, students did very little talking as they asked only a few questions. There was not a discussion that compared the energy diagrams of the different groups. During Activities 5 and 6, students worked in groups; 1st block did not have many questions while 3rd block asked factual questions. The computer simulation in Activity 7 uses evidence to answer the questions and the energy diagrams produced with the unknown will have variations from group to group; however, a class discussion of the variations did not occur.

The role of the teacher in Activity 1 was that of a facilitator as the students worked through the lab in groups; however, the questions during the discussion/lecture at the beginning of the hour were more factual resulting in a code in the middle of the spectrum. For Activity 2, the “Do Now” asked the students to predict a graph using Newtonian physics to describe the characteristics of light shown on a graph using quantum physics. This was open-ended and students drew their graphs on the chalkboard. This was followed by a lecture which results in the teachers as a source of knowledge. Students worked in small groups as they collected data so Activity 2 is coded in the middle of the continuum. A power point presentation was used to review Activity 3 which places it closer to the less inquiry-based side of the continuum. During Activities 4, 5, 6, and 7, the teacher was a facilitator. Additional hands-on activities during Activity 5, particularly in 3rd block, increase that role; however, beginning discussions included mostly close-ended questions and there were no discussions of the data so these activities are coded in the middle of the continuum.

When considering classroom activities, Activities 1 and 2 are inquiry-based. The data collected in these activities are used to look for patterns and compare and contrast the characteristics of the light sources. There are specific answers developed in Activity 3. The computer simulation in Activity 4 follows a process to produce energy diagrams but different groups finish with different diagrams so Activity 4 was placed in the middle of the continuum. Activities 5 and 6 produce specific answers as they help students to understand how this information is applied in real life so they are less inquiry-based. However, the addition of lab activities to Activity 5 moves it closer to the middle of the continuum. The first half of Activity 7 produces energy diagrams which may show differences between lab groups; however, a class discussion did not occur so this activity is coded in the middle of the continuum.

The rating for emphasis looks different when compared to classroom activities. The lecture for Activity 1 was about quantum physics which is very abstract. The activity itself used familiar objects such as lamps and LEDs. This places the activity in the middle of the continuum Gas lamps and spectra are not used by students on a daily basis; however the last question in Activity 2 determines the gas in fluorescent bulbs which is a practical application. Activity 3 is very abstract. The spectra in Activity 4 are abstract for the students as well. Activities 5 and 6 emphasize that scientists use this information in practical ways. The computer simulation in Activity 7 constructs light spectra which are abstract; but it reconnects with the LED which is not abstract so this activity is coded in the middle of the continuum.

For instructional strategies, all of the *VQM* activities are written with a balance of content and process with the intent of collaborative work or class discussion. Activities 1 and 2 were coded along the middle of the continuum because the lectures were more content based. The discussion of energy diagrams with Activity 3 was mostly content based. Activity 4 did not have a discussion so the students did not see the differences in their energy diagrams placing the activity along the middle of the continuum**.** The students worked in groups for Activities 5 plus the addition of hands-on processes, places this activity on the more inquiry-based side of the continuum. Activities 6 and 7 began with a lecture/discussion of the Periodic Table and some LED related vocabulary. The questions were mostly close-ended and there was no discussion of data results. Students worked in small groups so these activities are coded in the center of the continuum.

The continuum for discussion shows all activities on the less inquiry-based side of the continuum. This occurred because all activities began with a lecture/discussion in which most of the questions where close-ended. A whole class discussion of the data from the groups as described by the teacher's guide did not transpire; however, there is evidence that the groups shared data individually.

Lab activities were conducted in Activities 1, 2, 4, 5 and 7. In Activity 1, the procedure is described in the handout but the students must use the data to look for patterns. They also compare and contrast different light sources. The activity ends with an open-ended application question. The same is true for Activity 2 however it ends with an application question that has only one answer. The procedure for the computer simulation in Activity 4 results in an energy diagram that can help students understand the spectral lines for hydrogen; however, the energy diagrams may be different for each group. The computer simulation in Activity 5 directs all groups to the same answer. Teacher D added 2 short, hands-on activities to be completed on the same day. The energy diagram produced in the first part of Activity 7 may have different results for each group. The rest of the activity directs the students to answers that depend on the color of the LED used. Activities 1, 2, 4, and 7 are coded on the more inquiry-based side of the continuum. Activities 3 and 6 are not lab exercises so they were not coded using this continuum

The last portion of the classroom observation protocol is a series of questions for the researcher's reflection and interpretation. The researcher's field notes were used to answer the questions. Researcher reflections and interpretations were coded into categories based on the questions that were asked: effective implementation, things not observed, alternative teaching strategies, student attitudes, instances of inequity, non-verbal behavior of the students, and concerns of the researcher. Researcher reflections and interpretations are presented by category in Data Table 4.38.

Table 4.37 Reflections: Teacher D

	Effective Implementation	**Things Not observed**	**Alternative methods**	**Student attitudes**	**Instances of inequity**	**Non-verbal behavior**	**Concerns**
Act. 1 1st bk	-Students on task -Teacher is facilitator	Didn't finish - evidence of understanding not observed	Less lecture and more discussion	-Students on task -Attentive during the lecture	None observed	During lecture: one stretch, one sleeping.	-Very little discussion so evidence of understanding not observed
Act. 1 3rd bk	-Students on task -Teacher is facilitator	Didn't finish - evidence of understanding not observed	Less lecture and more discussion	-Students on task	None observed	Slouching One female braided another's hair	-Very little discussion so evidence of understanding not observed
Act. 2 1st bk	-The lecture is pretty detailed. -Students on task -Teacher is facilitator	Didn't finish - evidence of understanding not observed	Less lecture and more discussion	-Students on task	None observed	None observed	Nice graph predictions but students didn't want to "share" the information.
Act. 2 3rd bk	- The lecture is pretty detailed. -Students on task -Teacher is facilitator	Didn't finish - evidence of understanding not observed	Less lecture and more discussion	-Students on task	None observed.	None observed	Nice graph predictions but students didn't want to "share" the information
Act. 3 1st bk	-Students completed as homework. -Do Now reviewed the eV levels of electrons	Did see energy diagrams as part of the discussion	None needed	Students on task while collecting data but less so during discussion	None observed	Note-writing and off-topic discussions.	None
Act. 3 3rd bk	-Students completed as homework. -Do Now reviewed the eV levels of electrons	Did see energy diagrams as part of the discussion	None needed	Students on task while collecting data but less so during discussion	None observed	None observed	None
Act. 4 1st bk	-Students on task -Teacher is facilitator	-Student interest during demonstration of Lab Suite -No discussion so evidence of	Less lecture and more discussion	Students on task while collecting data but less so during discussion	Most questions were answered by one student	None observed	-Difficulty keeping students on task in lab -Problems getting

		understanding not observed					logged on to computers.
Act. 4 3rd bk	-Students on task -Teacher is facilitator	-No discussion so evidence of understanding not observed	Less lecture and more discussion	Some students on task while others are not	None observed	Students were moving from group to group for undetermined purpose	-Very little discussion so evidence of understanding not observed
Act. 5 1st bk	-Students on task -Teacher is facilitator .	-Did not move on to the next activity when finished -No discussion so evidence of understanding not observed	Have the next activity ready for those students who finish early	Some students on task while others are not	Students answered the questions in unison.	A student was constantly tapping his foot during discussion.	-It didn't take as much time as expected. -Very little discussion so evidence of understanding not observed
Act. 5 3rd bk	-Students on task -Teacher is facilitator	-No discussion so evidence of understanding not observed	None needed	Students on task.	Students answered the questions in unison.	Students were moving from group to group for undetermined purpose	The addition of the canister activity helped the class stay focused, but class still ended early
Act. 6-7 1st bk	-No discussion so evidence of understanding not observed	-No discussion so evidence of understanding not observed	More discussion	Students on task	None observed	Lots of yawning during the introduction	-Dry ice was a distraction -Very little discussion so evidence of understanding not observed
Act. 6-7 3rd bk	-No discussion so evidence of understanding not observed	-No discussion so evidence of understanding not observed	More discussion	Students on task while collecting data but less so during discussion	None observed	Lots of standing around and tossing pencils up and down	-Very little discussion so evidence of understanding not observed

The category for effective implementation requires the researcher to determine if the teaching strategies advocated by the *VQM* program are effective. Based on researcher reflections and interpretations, Activities 1 and 2 were effective. The students stayed on task and their data showed "correct" eV values and spectral diagrams. Problems with the equipment were easily fixed. Activity 3 was discussed at the beginning of the class and assigned as homework which worked well. The students worked on Activity 4 at their own pace; however, a discussion of data did not occur which reduced effectiveness. Activities 5, 6, and 7 did not include a class discussion. Most questions during 3rd block were about the "canister" activity. The students seemed to understand as there were few questions.

There were instances when the students were not finished with an activity at the end of the block. When this occurred in Activities 1 and 2, there was little evidence of student understanding. The discussion for Activity 3 followed the questions that students did not understand when they attempted to do the activity as homework. During Activity 4, a discussion did not occur so the differences in the energy diagrams produced by different groups were not observed. Discussion of data did not occur for Activities 5, 6, or 7 so student understanding is undetermined.

Alternative strategies that the instructor might have used for most of the activities include less lecture and more class discussion of results and verbal student presentations of data. This would allow more comparisons and the opportunity to check for student understanding. Teacher might have given a briefer explanation of the "Spectroscopy Lab Suite" that is to prevent boredom. Since one class finished early, have the next activity could have been ready to go just in case. The addition of the canister activity for the next block was an effective use of class time. Although only one student asked the majority of the questions during the Activity 3 discussion, equity was not an issue for this teacher.

Most of the notable nonverbal behavior occurred during the lectures and included sleeping, hair braiding, toe tapping and note writing. There were a few instances when students seemed to wander around the lab for no purpose during the activities. There are only a couple of major concerns. Students did not want to share the graph prediction during Activity 2. It seemed difficult to keep the students focused on Activity 4. Activities 5 and 6 did not take as much time as anticipated. There was no way to determine if the students understood any of the information because of the lack of discussion.

5. Field Notes – A summary of the interviews and observations that include the researcher's reflections and impressions help to establish themes in the teaching strategies data and show how it is related to the professional development. It also shows how the teaching strategies influence student learning. Field note data are embedded in the analysis of the reflections for the classroom observation protocol and learning results.

Since the teaching strategies are the focus of the classroom observations, the strategies used for each activity are described. These are based on the Classroom Observation Protocol and the researcher's field notes.

Activity 1

Teachers A and D provided data for this activity because Teachers B and C did not provide a videotape for Activity 1. This activity is hands-on and both teachers followed the activity as written. Teacher A included a whole class discussion. Teacher D preceded the activity with an introductory lecture.   Both teachers explained the activity before starting. Teacher A also related the information to previous lessons and provided a rationale. The students at both schools completed the hands-on activity. Those from School D also listened and took notes. Both schools used similar materials; the hand-out, lab equipment, whiteboard or chalkboard. The lecture for Teacher D also involved computer based technology and an LCD projector. In addition, the lab stations included some "make-shift" circuits because there were not enough circuit boards for the number of lab groups. The assessment strategies for both teachers included discussion and recitation responses and moving from group to group to observe student work. The major emphasis for both teachers included understanding science concepts, following a written procedure and collecting data. Minor emphasis was placed on learning facts, assessing prior knowledge, learning real-world applications, engaging in thinking skills and developing skill in working collaboratively.

Activity 2

All teachers provided data for this activity. This is a hands-on activity. Teachers A, C and D facilitated this activity as students worked in groups. Teacher B led the students through the activity question by question until they reached the section on LEDs which required the circuit boards. All of the teachers either explained the activity or provided an overview at the beginning of class. Teachers A, B and D also provided the rationale. Teachers A and B related the information to previous lessons. All of the teachers used the hands-on activity and whole class discussion. Teachers A and D had a short lecture at the beginning of the activity. Teacher B did a demonstration for her 5^{th} hour class. Students from all schools completed the worksheet and participated in a hands-on activity. Students at School C also read aloud. Students at School D made predictions with a graph and took notes as part of the "Do Now" activity. All of the schools used the same basic lab equipment and the handout. Teachers A, B and D also used a whiteboard or chalkboard. Teacher C and her students produced a black paper "tent" to provide darkness to take data in the classroom. Teacher D used computer based technology and an LCD projector for the lecture. Assessment strategies for all teachers included discussion and recitation responses.

Activity 3

This activity is a series of questions that builds the model of the energy diagram. It is a paper/pencil activity. Teachers A and B assigned this to be done in class. Teacher C assigned this as homework but the students did not do the assignment so it was then done in class. Teacher D assigned this activity for homework. During class, the "Do Now" activity contained questions to check for understanding. In addition, students were allowed to ask questions about the assignment before handing it in. The introduction was an explanation that provided the rationale or related the information to a previous lesson. Teacher B specifically used last year's chemistry class. The modes of instruction for all teachers included whole class discussion and student solving problems in small groups. Teacher A added a video and Teacher D added a lecture. All students completed the hand-out. Students in Schools A and D listened and took notes. Materials used included the hand-out and computer based technologies and projector for the video and lecture. Assessment strategies for all teachers included discussion and recitation responses.

Activity 4

This is a computer simulation that produces a possible energy diagram for the hydrogen atom. Students in all schools worked in small groups on this activity. All the teachers gave an explanation of how the simulation works. The major mode of instruction for all teachers was students working on the computer. Teachers A and D added a short lecture. Teachers C and D held class discussion as well. The students completed worksheets and worked on the computer. Students in School D also took notes. Teacher A added a video to this activity. Materials used were the worksheets and the computer simulation. Assessment for Teachers A, C and D were based on discussion and recitation responses. Teacher C also had a short-answer test. Assessment was not observed in School B.

Activity 5

This is an application activity that uses an absorption spectrum to look for a planet that is similar to Earth. This activity was completed by Teachers A, C, and D. All of these teachers explained the activity. Teacher D also provided and overview and related the lesson to previous lessons. The major modes of instruction for all three teachers included students solving problems in small groups and working through a worksheet. Teacher D also included a lecture/discussion. The students in all three schools completed worksheets. Students from School D took notes and completed a hands-on activity as well. Materials used included only the worksheets for everyone except students from School D who used lab equipment for the hands-on activity. Assessment for the three teachers was based on discussion and recitation responses. Teacher C gave the post-test on the same day Activity 5 was completed.

Activity 6

Teachers A and D completed this activity. This activity is a computer simulation. Teacher D included a lecture/discussion to review the Periodic Table. Both teachers explained the activity before starting. Teacher D also related the information to previous lessons. The students at both schools completed the worksheet and worked on the computer. Those from School D also listened during the lecture/discussion. Both schools used similar materials; the hand-out and computer-based technology. The lecture for Teacher D also involved computer based technology and an LCD projector and the chalkboard. The assessment strategies for both teachers included discussion and recitation responses.

Activity 7

Teacher D is the only participant in the observational study who completed this activity. It was finished by the students during the same block as Activity 6. As a result, the description of the two activities is identical.

Overall Analysis of Activities 1-7

The overall emphasis was coded using a list of choices on the Classroom Observation Protocol. The major and minor emphases for each teacher were determined by the outcomes of the activities, the types of questions used by the instructor and the amount of time spent in lecture, discussion, and lab. The major emphases for Teachers A and D across all activities included understanding science concepts, following a written procedure and collecting data. Minor emphases were placed on learning facts, assessing prior knowledge, learning real-world applications, engaging in thinking skills and developing skill in working collaboratively. Teacher B emphasized learning facts or definitions, understanding science concepts, and collecting data. Minor emphasis was placed on assessing prior knowledge, following a written procedure, interpreting data, and developing skill in working collaboratively. Similar processes where emphasized by Teacher C. Her major emphasis was placed on understanding science concepts, following a written procedure, and interpreting data. Minor emphasis was placed on learning facts or definitions, assessing prior knowledge, learning real-world applications, collecting data, and developing skill in working collaboratively.

Student Learning

Five sources of data were collected from the students in the participating schools; (1) Science Laboratory Environment Inventory (SLEI) which the students completed before beginning the *Solids & Light* unit; (2) Interviews which were conducted on the day of the personal observation of the classroom; (3) Pre-test/Post-test which were administered before the unit and again after the unit; (4) Student Questionnaire which was completed by the students after the unit was finished; and (5) Field Notes which were prepared by the researcher has observations occurred.

1. Science Laboratory Environment Inventory (SLEI) – The Science Laboratory Environment Inventory (Appendix B) is a survey that determines the classroom climate which has an effect on student achievement. In its original form, the SLEI asks 35 questions to determine the students' perception of the class as a whole for five areas that influence classroom climate: student cohesiveness, open-endedness, integration, rule clarity and material environment

(Fraser, Giddings, McRobbie, 1995). For this study, the survey was modified to include only open-endedness, integration and material environment. The students were asked to rate 21 statements that address the science classroom using the responses: almost never (1), seldom (2), sometimes (3), often (4) or very often (5). Several of the statements were written in the opposite direction and marked with an "R" to show that they were reversed. The average mean score for each of the three categories was tabulated and used to calculate a percentage that represents the perceptions of the students prior to the *Solids & Light* unit. The percentages are found in Data Table 4.39.

Table 4.38 SLEI Percentages

	Open-Endedness %	**Integration %**	**Material Environment**
School A	0.46	0.64	0.66
School B	0.53	0.69	0.75
School C	0.46	0.64	0.53
School D	0.60	0.78	0.80

Open-endedness reflects a divergent approach to laboratory experiments (Fraser, Giddings, McRobbie, 1995) which would include inquiry activities. School D has the highest rank with a 60% rating in this category. Students perceive that the classroom is more divergent but not completely open-ended. Schools A and C both scored 46% which reflects less open-endedness. The perception is that these classrooms are less divergent but there are some open-ended activities. School B has a 53% so some activities are open-ended and some are not. The integration category shows the student perception of the relationship between the labs and the classroom content (Fraser, Giddings, McRobbie, 1995). All of the schools have a 64% or higher which reveals high integration of class work and lab work. School D has the highest rank with a 78% while Schools A and C are the lowest with 64%. The material environment determines the student perception of the adequacy of the equipment in the laboratory (Fraser, Giddings, McRobbie, 1995). School D, again, has the highest rank with 80%. This school is the largest of the schools in this study. In the middle are School A with a 66% and School B with a 75%. School C has the lowest rank with a 53%. This school is the smallest of the schools in the study. It has less resources and the physics classroom is set up in a room that was originally built as a greenhouse. Overall, students believe that they have the needed materials most of the time.

2. Interviews - The interview questions (Appendix B) are open-ended so the analysis was determined by the topics of the questions themselves. Students were asked to describe the activity that they had worked on that day, whether there were any problems and if so, did they fix it themselves or receive help, tell what they learned that day and if they had any questions they would like answered. The interviews were completed at the end of the class period on the day the researcher observed the class in person. Students were asked to volunteer and the questions were asked to a group of students rather than individuals. Student responses can be found in Data Table 4.40.

Table 4.39 Student Interview Responses

	Act # and Topic	Problems	Received help	Learning	Questions
A	Act. 3 - light emission, energy lost and gained and the energy of photons.	- Burned out light bulbs. so we shared -Spectroscopes don't work well. -Color blind student	-Minimally -This is learn yourself	-An electron attached to an atom has negative energy. -When energy is lost, photons are emitted	None
B 2nd	Act. 2 - It was about LEDs.	The spectroscope		-Differences and similarities between light sources. -Know what a photon is. -Different colors have different energies	No time for this
B 5th	Act. 2 - It was about different spectra.	The spectroscope		Differences and similarities between light sources.	Not really
C	Act. 2 - It was about spectrum and LEDs	-Not really - the spectroscope		Energy in light depends on brightness and color	Think we are doing okay
D 1st	Act. 1 - Comparing LEDs and incandescent lamps and voltages and colors	LEDs burning out	Both	-LEDs start white and as voltage increases color changes -Incandescent are opposite colors	-How LED goes through color spectrum. -Why blue LED takes more voltage
D 3rd	Act. 1 - It was about LEDs, Christmas lights	-No -Yellow LED did burn out	Yes	-The thresholds of LEDs are not the same.	Are there more than lamps, LEDs, and

	and incandescent lamps			-Same maximum value of LEDs	Christmas lights other visible lights?

* School A students did not like the video shown in class that day.

The schools were completing Activities 1-3 when the personal observations occurred. During the interviews, the students were able to describe the activity number and the general topic of that activity. School D had just begun Activity 1 so students explained that LEDs of different colors have different threshold energies. One group of student inaccurately described the LED as changing color as the voltage increases. While most LEDs look white below the threshold voltage, their color does not change (from yellow to red for example) as the voltage increases. Schools B and C were working on Activity 2. Students from both schools described the activity as being about LEDs and spectra. They learned that there are differences between LEDs, incandescent bulbs and gas lamps. They also explained that there is a relationship between energy and color. School A was focused on Activity 3. Students learned that the electron has a negative energy value when it is attached to an atom and that when energy is lost, a photon is emitted. Problems that were common to all schools include difficulties with the spectroscopes and LEDs that burned out during the lab. While the teachers did provide help, the students were also able to solve some of the problems themselves. Students from schools A, B, and C did not have any additional questions. Students from School D had questions about the voltage in blue LEDs and the spectrum of LEDs. One group was curious about other light sources as well.

3. Pre-test/Post-test – Questions on the pre-test and post-test (Appendix B) assess the unit objectives. Students were given the pre-test before beginning the *Solids & Light* unit. The post-test was administered as each teacher finished the last activity that they completed. Standard deviation and t-scores for each school individually and for all school combined were calculated to determine the level of student learning. The results are found in Data Table 4.41.

Table 4.40 Testing Results

	Pre-test mean	**Post-test mean**	**Pre-test Standard Deviation**	**Post-test Standard Deviation**	**Cohen's d**	**Effect size r**	**P(T<=t) Two-tail**
School A n = 6/6	3.666667	35.5	2.48	4.54	8.7	0.97	1.19E-08
School B n = 20/19	6.9	15.94737	3.39	6.02	1.9	0.68	5.04E-06
School C n = 2/2	6	20	0	0	N/A*	N/A*	#NUM!*
School D n = 30/29	7.1	22.96551724	4.06	7.54	2.6	0.79	8.37E-13
All Combined n = 59/57	6.644068	21.77193	3.65	8.85	2.2	0.75	4.33E-23

*too few students for valid calculation

The mean test score for all schools increased both individually and combined. All individual student scores increased as well. The intention of the unit is student learning so an increase in test scores was expected. The standard deviation for all schools indicate a larger range on the post-test for all schools except School C which had only two students whose scores on the pre-test were identical and on the post-test were very close together. The two-tailed t-scores at a probability of 0.05 are above the critical value for all schools except School C. The value of r for the Effect size is above 0.371 which is a large effect size. As such, it indicates that the increase in test scores was significant for all Schools except School C. With only two students in the physics class, School C did not have enough students for the calculations to be valid. School C was included in the calculations for all schools combined and the t-scores for this were above the critical value and r is above 0.371. The data indicates that student learning during the *Solids & Light* unit was significant.

4. Student Questionnaires – Students of teachers who participated in the observational study were asked to complete the Student Questionnaire (Escalada, 1997) which discussed Activities 1-6. (Appendix B) In these activities, the students compare incandescent bulbs with LEDs, observe emission spectra of bulbs, LEDs and gas lamps, and complete energy diagrams. They use a computer simulation to combine the information from the previous activities and then complete two application activities. Analysis on the open-ended questions is based on the topics of the questions. The questions pertaining to the topics learned is further divided into five categories based on ideas that emerged from the responses. The categories are light sources, energy, spectra, energy diagrams and nothing. A summary of the students' comments is found in Data Table 4.42.

Table 4.41 Student Comments on Learning

	Light Sources	**Energy**	**Spectra**	**Energy Diagrams**	**Learned Nothing**
School A n=7	Four comments about the differences between different types of light: LEDs, gas lamps, and incandescent lamps	Four comments about the relationship between color and energy as observes in voltages or eVs	Five comments about using the spectrum and/or comparison of emission and absorption spectra	Three comments about the use of energy diagrams	
School B n=27	15 comments about the differences between different types of light: LEDs, gas lamps, and incandescent lamps One comment about incandescent light bulbs get hot, while LEDs do not	12 comments about the relationship between color and energy as observes in voltages or eVs One comment about different colors of lights work at different voltages	11 comments about using the spectrum and/or comparison of emission and absorption spectra One comment about spectroscopes were fun and helped explain the light spectrum very well	One comment about: -Energy diagrams, allowed us to explore light patterns thoroughly -The flow of electrons	One comment about: -Not much at all -Re-learned a lot -Well nothing new really – just a review of last year
School C n=2	Two comments about the differences between different types of light: LEDs, gas lamps, and incandescent lamps	One comment about energy frequencies that corresponded with each color	One comment about different gases correspond with different light spectrums		
School D n=27	16 comments about the differences between different types of light: LEDs, gas lamps, and incandescent lamps	Four comments about the relationship between color and energy as observes in voltages or eVs One comment about different energy levels of the colors of light and about photons and emissions	21 comments about using the spectrum and/or comparison of emission and absorption spectra One comment about: -Different elements can be identified by their color spectrum -There is also more than one kind of spectrums which are discreet and continuous	Seven comments about the use and construction of energy diagrams	None

Students from all schools described learning about the differences between an incandescent lamp, an LED and a gas tube including the concept that they all produce different spectra. These statements coincide with objectives from Activities 1 and 2. Students from all schools also had individuals who explained that the energy in voltage or eV was related to the color of light that was produced either by the LEDs or in the spectra of the lights that they observed. The objectives from Activities 1 and 2 describe these concepts. In addition to the spectra, students from Schools A, B, and D explained the difference between emission and absorption spectra which is an objective from Activity 5 and School D mentioned discreet and continuous spectra which is a concept from Activity 2. Students from three of the four schools described the use or construction of energy diagrams which matches the objectives of Activity 3. A total of four students stated that they had learned nothing in this unit. Most of these students were from School B where a similar unit had been done in chemistry the previous year.

The topic for the next question was to describe the similarities and differences between this unit and those done previously in the class. The categories for this section of the questionnaire are similarities and differences. The description given by the students are found in Data Table 4.43.

Table 4.42 Students' Perceived Similarities and Differences

	Similarities	**Differences**
School A n=7	-Conservation of energy -You start with the basics and gradually work onto the more complex system -we used a spectrometer.	-We worked on kinematics -Not previously studied lights or anything like this -They are different. However, it is a 100% hands on learning, practical applications.
School B n=27	-You complete several activities pertaining to one overall unit and break them down to understand the unit as a whole in smaller steps -Did not seem out of the ordinary -Nine comments about the activities being similar to chemistry -Its just like a science experiment -Kind of similar to previous class activities	-They were more in depth and we learned a lot more -It was something you could see. More hands-on and a lot of papers. We didn't have to fill out a V chart -This is more of a chemistry project than a physics project. -Other units entailed motion, acceleration and Newton's Laws -Different because of all the packets that went with it! have not dealt much with eV and different light sources. -Never done anything like these activities
School C n=2	-We worked in a small group	-Didn't have to use as much calculation -The materials we used were different.
School D n=27	-Ten comments about doing hands-on activities and doing labs frequently -Two comments about working with computers frequently -Three comments about working with light	-Except we usually work on the labs a little bit longer instead of one lab each time -Are very complicated and harder to get something out of the lab. -Terminology seems a little more advanced

	spectra previously. -We have already worked with energy diagrams, circuits, charge on electrons -We were given a lab worksheet, and we would just go through the sheet until we were done -Similar in that we split into groups and brainstorm -Recording data and observations help us to understand concepts	-Before, we did more hands-on activities -We usually have longer labs or they are more complicated. Usually, we have to figure out everything on our own. The labs we did with these activities give a lot more information -There is a lot more reading involved -Different in that the activities usually are step-by-step

The intention for asking about similarities and differences between this unit and previous activities in class was to determine if the students were familiar with inquiry learning. The students answered the question with a much broader scope which included the physics topics that they had previously encountered. For the similarities category, the students from School A describe doing labs that start with the basics and gradually become more complex. They had also learned about conservation of energy and the spectroscope prior to starting *Solids & Light*. Students from School B described the unit as "just like a science experiment." There were several activities that helped them understand the unit in smaller steps. Many of the students said that they had done a similar unit the previous year in chemistry. The only similarity observed by the students in School C was that they worked in a small group which is interesting because there are only two students in the class. The students from School D had many comments about frequently doing labs that included hands-on activities and using the computer. One student commented that "observations help us to understand concepts." Some of them had learned about light spectra, energy diagrams, circuits and electrons previously.

The differences described by the students in School A include that they had not studied light before, they had been working on kinematics and that this was different because it was more hands-on and practical. The comments from students at School B were similar in that some students said that they had not previously studied light, eV, or "anything like these activities." They felt that this was more in depth, more hands-on, and a lot of paperwork with all of the packets. They had previously studied motion, including acceleration and Newton's laws. Students from School C described using different materials and fewer calculations in this unit. The comments from the students in School D included the ideas that the activities were a different format; one lab each time, shorter and less complicated, and not step-by-step. This was contradicted by a student who felt that they did more hands-on before the unit started. One student thought there was more reading in this unit. Yet another student felt this unit was more complicated which was reinforced by a comment about the terminology being more advanced.

The last portion of the Student Questionnaire included a series of statements that reflect the students' perception of learning in the *Solids & Light* unit. The students rated each statement on a 5 point scale using the responses definitely false (1), false (2), neutral (3), true (4) or definitely true (5). The mean score for each of the statements was tabulated for each school. The results are found in Data Table 4.44.

Table 4.43 Student Perception of Learning

Survey statements from Student Questionnaire 1		**Average score**
The current-voltage investigations helped me understand how LEDs differ from other light sources	School A	4.14
	School B	4.0
	School C	4.0
	School D	4.18
Average of all schools		**4.24**
Observing the spectra of gases helped me understand how light is emitted by an atom.	School A	4.14
	School B	3.58
	School C	3.5
	School D	3.90
Average of all schools		**3.78**
The potential energy diagram is a useful representation of the atom.	School A	3.57
	School B	3.54
	School C	3.0
	School D	3.83
Average of all schools		**3.49**
The *Spectroscopy Lab Suite* program taught me how electrons are involved in the emission of light from an atom.	School A	3.43
	School B	3.58
	School C	4.0
	School D	4.26
Average of all schools		**3.82**
The *Spectroscopy Lab Suite* program helped me understand why light from one type of atom is different from light from another type of atom.	School A	3.57
	School B	3.88
	School C	4.0
	School D	4.1
Average of all schools		**3.89**
I can use the potential energy representation of an atom to explain the spectra that I observed.	School A	4.14
	School B	3.83
	School C	3.5

	School D	3.88
Average of all schools		**3.84**

Students from all schools ranked all of the statements between 3.49 and 4.24 on the 5 point scale representing the students' perception that they learned the concept in each statement. The statement about understanding the difference between LEDs and other light sources had the highest ranking with an average of 4.24 which indicates the students felt this statement was "true." Understanding potential energy diagrams was ranked the lowest with an average of 3.49 indicating an average response between "true" and "neutral." Students from School D gave the highest ratings overall, followed by students from School A, then students from School C and lastly students from School C. This indicates that the students in Schools A and D perceived a higher level of learning. The post-test scores show that this perception is correct.

5. Field Notes – The notes and reflections of the researcher are qualitative data and are embedded in the data for student behavior in the Classroom Observation Protocol.

Summary

In the professional development data, the teachers who participated in the institute made positive comments about the summer institute stating "Great workshop" and "I enjoyed this workshop." They also learned a variety of information including matter/anti-matter, relativity, cosmic rays, and how much we really don't know about the universe. The instruction with the *VQM* program added a better understanding of the light spectrum and the differences between light sources as well as how to use the software and teacher materials in the classroom. There were comments such as "I uncovered some of my own misconceptions that will inevitably be present in the minds of the students I teach" and "this workshop helped me better understand this activity and how I might be able to implement it into my physics class." In addition, 31% of the participants strongly agreed and 63% agreed that the materials from the institute would be useful in the classroom.

However, there were some concerns, particularly about the use of the spectroscopes. The more expensive spectroscopes have scales with the wavelength and eV values; but, these are difficult to see if there is too much or not enough light. It takes practice to use these effectively.

In addition there were problems with burned out bulbs and malfunctioning voltmeters which participants felt might make Activities 1-2 difficult to do with students. Another concern was the perception the teachers had that this unit does not teach any of the tested standards. This concern will be addressed later in chapter 5. A third concern was the format of the handouts. The questions were not numbered and the spaces to answer the questions do not always immediately follow the questions. Teachers wanted to be able to modify the PDF to fit their students' needs.

A majority of the institute participants chose not to use the *VQM* materials. The top reasons cited include "doesn't fit into my curriculum," "not enough time," and "implementation time is too long." In the end, most of the teachers who chose to use the *VQM* program during the 2007-2008 school year had used or been trained with the program previous to the summer institute. Only one of the participants had not used the program with students prior to the study and she had also volunteered to be a lead teacher for QuarkNet.

Instructional Strategies data indicates that all four of the teachers participating in the observational study followed the order of the activities and used the equipment as outlined by the teacher's guide for the *Solids and Light* unit. They used small groups for the hands-on activities and computer simulations. Teacher A used white boards for data sharing in Activities 1 and 2. He added videos to Activities 3 and 4. Teacher A functioned as a facilitator answering questions asked by students through the *Solids and Light* unit. In Teacher B's classes, the discussions were almost all close-ended question. She gave very brief introductions and at times it appeared these were done because of a student question. Activity 2 was done as a "whole class" group and very teacher directed as she read questions and elicited answers from the students. The students worked individually on Activity 3. Teacher B became a facilitator on Activity 4. Teacher C instructed a class of two students. She sometimes participated as a group member and sometimes left the girls to work alone. At several times, she looked up the answers in the teacher guide to confirm the answers with the students. All of Teacher D's classes began with a "Do Now" activity that generally included questions to answer. Some of the questions were open-ended, application questions and some were close-ended questions. This was followed by a class discussion of the answers and this was usually followed by a lecture or lab directions for the day. The students would then get into their lab groups and work on the activity for the remainder of the block. Teacher D became a facilitator answering student questions as they arose.

All of the teachers who participated in the observational study used instructional strategies that are advocated by the VQM program. These strategies include whole group discussion and the use of small groups during hands-on activities and computer simulations. An explanation was given at the beginning of each activity that included procedures, rationales, and/or relationships to previous activities. The classrooms became student-centered with the teachers acting as facilitators as the activities were completed.

The student data indicated that students at Schools B and D perceived their school to be more open-ended than students from Schools A and C, which both scored below 50% on the SLEI. All four schools have high percentages of students that agree that the information taught in class integrated with information in the lab activities. Students at Schools A, B, and D perceived, according the SLEI, that their schools had adequate equipment for lab activities. School C, the smallest school, had the lowest perception of having adequate equipment for lab activities. Data from the questionnaire indicates that students have the perception that they learned information about light from the *VQM* unit. Results from the post-test confirm this learning with t-scores that are above the critical value at a probability of 0.05 and a large effect size.

CHAPTER 5 - Conclusion

Introduction

Chapter 5 includes a summary of the study, conclusions from analysis, discussion of the limitations of the study, recommendations for future research and the researcher's final thoughts.

In this naturalistic inquiry case study, the researcher observed the professional development and implementation of *Solids & Light* which is a unit in the *Visual Quantum Mechanics* (*VQM*) program. In addition, the student learning of the concepts taught by this unit were examined. During the summer of 2007, 20 physics teachers participated in professional development sponsored by the Kansas State University QuarkNet group. These twenty teachers participated in the initial stage of data collection related to professional development. Information related to the professional development was gathered from five sources: the QuarkNet Summer Institute Evaluation form, *Visual Quantum Mechanics* journal entries, *Visual Quantum Mechanics* Email Survey, field notes and *VQM* documentation. Four teachers who participated in the professional development at the QuarkNet summer institute volunteered to participate in the observational study that was carried out during the academic year 2007-2008 to provide additional in-depth data related to the instructional strategies used during the implementation of the *Solids & Light* unit. Each of these four teachers completed an informational form and two questionnaires.

The Classroom Observation Protocol was used to examine the implementation of the program as the four teachers videotaped multiple activities from *Solids & Light* and the researcher visited their classrooms. Field notes were used as additional data while completing the protocol. Each teacher who implemented *VQM* was interviewed at the time of the classroom visit and again at the end of the unit. The students in the classes of the teachers who participated in the observational study completed the Science Laboratory Environment Inventory to determine the students' perception of the lab environment. A pre-test and post-test was administered to determine students' learning. All students also completed one questionnaire and selected students were interviewed at the end of the classroom observation.

Summary

The data for this study were divided into three sections: professional development, instructional strategies, and student learning. The QuarkNet Evaluation form revealed that the teachers attending the QuarkNet Institute in the summer of 2007 learned about matter/antimatter, Feynman diagrams, the theory of relativity, and instructional strategies that are used in physics classes as they came to understand "how much we don't know." The *VQM* journal entries indicated that the teachers liked the *VQM* program and that they had arrived at a better understanding of the content and teaching strategies. They were also concerned about the amount of reading that is required of the students and the format of the worksheets. The *VQM* Email survey determined that the most important reasons for not implementing the *VQM* program in the classroom were that there is not enough time in the school year and that the program does not fit into the curriculum. Field notes disclosed that there were concerns with the use of the spectroscopes and the technical problems with the voltmeters and light sources along with a discussion of how to solve those problems. For those that purchase *Visual Quantum Mechanics*, there is additional teacher information in the documents provided with the program.

The Participant Information Form indicated that the four observational study participants had used inquiry activities and computers in the classroom before beginning the *Solids & Light* unit. Teacher Questionnaire A revealed that the teachers felt that their students had met the prerequisites before starting the program. The teachers found that their students learned about atomic spectra and energy relationships without any difficulties in the unit. Each activity was rated for its effectiveness in meeting the objectives. Activity 2 received the highest average rating and Activity 6 received the lowest average rating.

The exit interview indicated that the *VQM* training was effective for two of the four teachers and the other two felt that they needed more time to prepare before using the program in their classes. Three of the four teachers really were not concerned about the science standards because the students were seniors and had already taken the science assessment. The fourth teacher believes that that the *VQM* program teaches some standards that could otherwise be neglected. The Classroom Observation Protocol indicated that the instructional strategies used by the teachers who implemented *Solids & Light* included small group work on hands-on activities and computer simulations, whole class discussion, videos and lecture. The typical introduction included an explanation of the activity and an overview or rationale for the activity. The teachers' individual teaching styles were evident in the data as well.

The students' perception of the open-endedness, integration and material environment of their school was rated using the SLEI. Two of the schools were less open-ended and two were more open-ended. All schools scored above 50% for integration and material environment. Interviews with students established that they could describe the information that they had learned that day. Their perception of learning, as shown by the Student Questionnaire, was that they did learn the content. Learning was confirmed by the pre-test/post-test results. The two-tailed t-scores were above the critical values at a probability of 0.05 for all schools for which data were examined by this statistical method. The effect size (r) for all schools, except School C with too few students, was above 0.371 which indicates a large effect size.

Conclusions

The first research question was "How does the professional development for *Visual Quantum Mechanics* influence teachers' implementation of the program?" To explore the answers to this question, the researcher has chosen to pose two other questions; (a) "How does the professional development affect the classroom implementation of individual activities within the program?" and (b) "What instructional strategies are most commonly used by the teachers using the *Solids & Light* unit?" Findings of the study under these separate aspects will be examined under these aspects.

How does the professional development for *Visual Quantum Mechanics* influence teachers' implementation of the program?

a. How does the professional development affect the classroom implementation of individual activities within the program?

1. Positive professional development experiences and the perception of adequate preparations do not necessarily lead to implementation.

The QuarkNet Summer Institute Evaluation Form revealed that 75% of the 20 teachers that responded felt that the opportunity to interact with teachers in physics was helpful. Positive experiences are reflected in comments such as "Great Workshop" and "Lectures were well received." One teacher "loved learning more historical aspects of who did what, when, how." The journal entries indicate positive experiences as well with one teacher commenting, "It was fun to investigate the LEDs." One teacher liked the activities because they could be used in the classroom. Yet another thought the program was good because the activities were interesting. All of the completed evaluation forms identified three topics that each individual teacher learned during the week.

Adequate preparation was indicated in both the evaluation form and journal entries. For example, 63% of the institute participants felt that the materials provided would be useful in the classroom and 56% felt confident to implement *VQM* in their classroom. The confidence of participants was disclosed by their statements of learning which included using resources, doing hands-on activities and having a better understanding of the spectrum. The journal entries that are teacher related revealed that the participants felt that they were better prepared to teach these activities. As one teacher put it, "I uncovered some of my own misconceptions that will inevitably be present in the minds of the students I teach. Uncovering these misconceptions here, will help me do a better job of addressing them as they show up in my students". Another teacher felt better prepared to use the activities. In addition, the "strategies/modification" category of the journals revealed how the teachers would use the activities in the classroom. One teacher would set up stations for the students to rotate through. Another thought that the equipment should be demonstrated for the students before starting the activities. Yet another would use more meaningful demonstrations while teaching the unit on light.

Even with all of the positive experiences, only 6 of the 20 institute participants implemented *VQM* during the 2007-2008 school year. Implementation of the *Solids & Light* unit was limited by teachers' limited time and their perceptions regarding a lack of alignment between the curriculum and the standards. According to the email survey, 9 of the 20 teachers felt that there was "not enough time in the school year" to implement the *Solids & Light* unit. One teacher commented in a journal entry, "I find the material very interesting, but I'm not sure about the amount of time that should be committed." Time limitations were intensified by the additional time teachers needed to feel adequately prepared to teach the unit, even when teachers reported feeling adequately prepared during the institute. There were 9 tallies on the email survey for "limited time to learn the program." These results later in the year contradicted the participants' earlier the perceptions of being adequately prepared. In addition, two of the teachers who participated in the observational study noted they needed additional time to prepare. Although Teachers B and D agreed in the exit interview that the *VQM* training during the institute was adequate, Teachers A and C stated that the training was not adequate. Teacher A felt that he "still needed to read beyond the training to become comfortable with the program before using it with students." Teacher C believed that the "activities were not taken in context with the entire unit." If a teacher does not feel comfortable with the materials, it reduces the chance that the program will be implemented. Teachers make decisions about what is best for their students, which translates to added time for preparation when students will benefit from the implementation of new activities.

The perceived alignment between the *Solids & Light* unit and the state science standards also limited implementation of the unit. The Likert scale on the email survey used the number 1 to represent the most important reason for not implementing *VQM*. The reason with the lowest average value (2.4) was that it "doesn't fit into the district curriculum." This concern was also mentioned by two teachers in the journal entries. As one of the teachers stated, "high school physics (according to state standards) is primarily mechanics." According to the field notes, state standards and the alignment with the *VQM* program were not discussed during the institute.

2. Teachers were less likely to implement activities they had not practiced themselves during professional development.

Those activities not completed during the institute were not implemented by all of the teachers with their classes. Field notes from the institute indicate that Activities 1, 2, 4, and 7 were completed by the teachers as students would do. Activity 3 was handed out and participants had the option to complete it. Some participants must have finished it because a comment in the journal entries said, "I can see that this activity would be a really useful preparation for activity 4." Activities 5, 6, and 7 were distributed as handouts and discussed. There was time to do them and most finished activity 7. The rest of the unit was handed out but not completed. All of the observational study participants extended their implementation through Activity 4. Three of the four finished Activity 5 and two of them finished Activity 6 with their students and Teacher D concluded the unit with Activity 10.

Discussion within the activities at the summer institute may have affected the discussions used with the students. During the professional development, the discussion of Activity 1 was modeled such that the teachers could see how the discussion would be done with students. Teacher A used a similar discussion with his class. While discussion occurred for Activity 2 during the professional development, it did not follow the lab questions as it would with students. Teachers A and B had some discussion with their students during this activity and Teacher D mentioned the data briefly at the beginning of the next class. Activity 3 was not completed by all of the institute participants and a whole group discussion did not occur. Two of the teachers who participated in the observational study did not discuss this activity. School C read through the activity aloud and answered the questions. School D included the discussion in a "Do Now" activity.

Activity 4 was discussed with the whole group at the institute. The discussion included how to address students' questions about the model that has been used in the simulation. Even with this discussion, none of the teachers in the observational study had this type of discussion with their students. The teachers may have been uncomfortable with the whole group discussions in the activities since modeling of the discussion technique did not occur during all activities during the institute. An additional aspect to discussions would be the role that the teacher is taking. At the institute, the role is as a student. While teaching, the role changes to that of the leader. While the leadership role was modeled, the participants did not practice that role.

3. Implementation of the *Solids & Light* unit was enhanced by repeated exposure to the activities to be implemented.

Of the 6 institute participants that implemented *VQM*, four of them volunteered to participate in the observational study. Three of these four teachers had previous exposure to the *Solids & Light* unit. Teachers B and C, as veteran QuarkNet members, had been introduced to *VQM* at an earlier workshop. Teacher D had taken a college class that taught the entire program. Teachers B and D had already completed the *Solids & Light* unit with students in previous years. Multiple exposure increases the perception that one is adequately prepared to use the program with students.

4. Implementation of the *Solids & Light* unit is influenced by leadership roles and additional support.

Those teachers who volunteered to be lead teachers for QuarkNet were given additional support from KSU, not only to implement the program, but to teach a workshop as well. This support included the purchase of the entire program, conference calls, and the ability to borrow equipment to do the activities. Teacher C felt much more comfortable with the unit after preparing to teach a professional development opportunity for other teachers. Since all of the study participants were also lead teachers, implementation of *Solids & Light* may be influenced by the QuarkNet support given to them.

b. What instructional strategies are most commonly used by the teachers using the *Solids & Light* unit?

1. Teachers implementing *Solids & Light* use the instructional strategies advocated by *VQM*.

All of the teachers introduced the day's activity with an explanation of the activities. Many times, that included a rationale for the activity and/or the activity's relationship to a previous lesson. Activities 1 and 2, which were hands-on labs, were completed in small groups. Activities 3 and 6 were paper/pencil activities completed in small group discussion or individually. Students worked in small groups as they manipulated the computer for the simulations in Activities 4, 5, and 7. Activity 5 demonstrates an application for the spectra from the previous activities. This is a computer simulation that relates spectra to star composition. Students then look for an Earth-like planet in Activity 6 which is a paper/pencil worksheet. In Activity 7, students return to the computer. In addition to working within a group, students were observed discussing data between groups. The teachers functioned as facilitators during the activities, answering students' questions as they were asked.

Several of the activities also encourage whole class discussion. The data on the whiteboards in Teacher A's room is evidence that students shared data. The discussion in Teacher B's class as she wrote the data on the chalkboard allowed the students to see the patterns in the energy levels of the LEDs. Whole class discussion usually occurred within a lecture at the beginning of the block for the students at School D.

2. Teachers implementing *Solids & Light* did not always use whole class discussion as advocated by *VQM*.

Whole class discussion did not occur as often as the teacher guide suggests. For example, the teacher's guide suggests that students report their eV values for the LEDs and then discuss the results. The discussion should follow the questions in the activity which asks for patterns and similarities and differences between the incandescent lamp and the LEDs. The student handout also indicates that a class discussion should occur after the data is completed on the Christmas bulbs. School A followed the suggestions for the incandescent lamp and LEDs but did not discuss the Christmas bulbs. School D embedded some of the information in the "Do Now" on the following day but the students did not discuss their results as a class. The student handout for Activity 2 indicates that a class discussion should occur after all groups have completed the data for the LEDs. The discussion questions focus on similarities and differences between the spectra of the incandescent lamp and LEDs. The students at all schools completed this activity in two days. At School A, a formal discussion did not occur on the first day. The second day began with a discussion of mostly close-ended questions. The teacher answered two of the questions when a student response was not given.

While the class data at School B was written on the chalkboard, most of the questions were close-ended. The teacher led the students through this activity and provided them with many of the answers. The 2nd hour class addressed the open-ended comparisons of the incandescent lamp and LED but the other class ran out of time so a discussion did not occur. At School C, the teacher functioned as a lab group member for Activity 2. The lab group did discuss the similarities and differences between the light sources as they wrote the answers on their papers. The students at School D traveled from lab station to lab station to complete the data for this lab. The groups did talk to one another to compare data but a formal whole class discussion of the data did not occur.

The teacher's guide suggests doing Activity 3 as homework and then discussing the results. Only Teacher D completed Activity 3 as homework with a discussion. The teacher's guide for Activity 4 suggests that the activity pages can be used as a guide for class discussion of energy levels. The energy diagrams of the groups will not be identical so it is suggested that the discussion include the limitations of the students' knowledge and of the model that they have produced. In addition, the student handout asks the students to compare their energy diagram with those of other groups and describe their similarities and differences. Teacher A began the block with a whole class discussion that consisted of nine close-ended questions and one open-ended question. Students answered the questions and the teacher elaborated on most of them as well. A discussion of the energy diagrams did not occur. Teacher B noted with the students that the diagrams are not identical but a discussion did not take place. School C also noted that diagrams would be different but with only one group, it would not be observed. Students at School D were working in groups and were comparing data between groups but a whole class discussion did not occur.

It is suggested in the teacher's guide that the first part of Activity 5 be done as homework followed by a short discussion before starting on the computer simulation and that the students should share the energy diagrams with others in the class. All participants that completed Activity 5 did the entire activity in class without any class discussion. Activity 6 is a paper/pencil activity which also can be completed as homework. The answer key in the teacher's guide states that some of the questions may be difficult for the students to answer. Student should try to answer them first and then discuss with the class because the object is to spark discussion. Teachers A and D did not have class discussions with this activity.

3. Teachers implementing Solids & Light modified the program to fit individual teaching styles.

While there were many similarities in the instructional strategies, the teaching styles of the individual participants did influence the implementation of the program. Teacher A used shorter introductions and allowed the students to work through the activities asking questions as they needed. He added videos to Activities 3 and 4. Classroom observations for Teacher B during Activity 2 show a very teacher-centered classroom, while there was a student-centered classroom for Activity 4. Students from this school rated the classroom as open-ended on the SLEI which indicates that Activity 2 may not have been typical for this teacher. The small class for Teacher C limits the types of activities that could be used because a comparison of group data cannot occur if there is only one group. The students frequently read the activities aloud which kept them focused and together as they worked through the answers. Creative problem solving occurred when they needed the classroom to be dark to take additional data for Activity 2. A "Do Now" activity that contained both open-ended and close-ended questions were presented at the beginning of each block in Teacher D's classroom. A lecture was added to each day's activities as well. The students tried to look at the light reflected from a whiteboard with the spectroscopes while they were completing Activity 5. An activity with a canister containing quarters was added to Activity 6.

The second research question was "How does implementation of *Solids & Light* affect student learning?" Again the researcher has opted to consider this by answering two related questions: (a) "How does student perception of laboratory experiences affect their interaction with *Solids and Light* materials?" and (b) "Do students develop a conceptual understanding of the quantum mechanics in the unit?"

How does implementation of *Solids & Light* affect student learning?

c. How does student perception of laboratory experiences affect their interaction with *Solids & Light* materials?

1. The students' perception of laboratory experiences did not affect their interaction with *Solids & Light* materials.

Students from all schools were more attentive during the lab activities than they were during the discussions, lectures and videos. There were common problems with the circuit boards, the yellow LED, and learning to use the spectroscopes. At all schools, students were able to describe both similarities and differences between the *Solids & Light* unit and their previous laboratory experiences.

On the Science Laboratory Environment Inventory (SLEI), students rated School A at 46% on the open-endedness and above 60% on both integration and material environment. This indicates that the student perception of the classroom is a less open environment with adequate materials used to complete labs that usually coincide with the content of the class. But these results also conflict with the student interview statements that stated that they had to teach themselves which would be more open-ended. Students were asked on the Student Questionnaire if the activities were similar or different in nature. One student felt that they were similar because they "start with the basics and gradually work onto the more complex". On the other hand, another student felt that they had "never done anything like this. All was new." Yet another student commented, "In order for us to learn, we had to do the activities." Furthermore, data from the Classroom Observation Protocol indicates that students were more attentive when the labs were occurring and less enthusiastic during the discussions and videos.

School B received high ratings for all categories on the SLEI with 53% on open-endedness, 69% on integration and 75% on material environment. This indicates that the students perceive their lab as usually open-ended with appropriate materials to complete labs that correlate with the classroom content. Comments from the Student Questionnaire indicated that *VQM* was perceived as similar to experiences they had in chemistry the previous year. One student stated that it is “just like a science experiment” and another said that it “did not seem out of the ordinary.” On the other hand, the differences that were mentioned included the increase in the amount of paperwork and that it was “more hands-on.” Data from the Classroom Observation Protocol reveals that during Activities 2 and 3, students had difficulties staying on task and participating in the discussions. They were more attentive when they used the computers for the simulation in Activity 4.

The SLEI ratings for School C were 46% for open-endedness, 64% for integration and 53% for material environment. This indicates that the students perceive their classroom as less open. While the labs are usually related to the class content, they have adequate materials to do the labs only about half of the time. These students described the *VQM* unit on the Student Questionnaire as similar to past experiences because they worked in a small group but different because there were less calculations and the materials were different. The Classroom Observation Protocol indicates that the students were enthusiastic during the labs, particularly on the energy diagram for Activity 5 but they were less excited about content during the reading and Activity 3.

School D received the highest ratings for the categories on the SLEI with 60% for open-endedness, 78% integration and 80% for material environment which strongly suggests that students perceive their classroom as usually open-ended with adequate materials to do labs that match the content in the class. Data from the Student Questionnaire reveals multiple statements to explain that *VQM* was similar to previous experiences because they frequently use the computers and also do hands-on activities and labs. Observations of the students moving from station to station with little direction from the teacher would support these statements. In another similarity a student stated that “recording data and observations help us to understand concepts.” Descriptions of differences include that there is more reading and that previous labs were more hands-on and longer or more complicated. The data from the Classroom Observation Protocol indicates that the students were on task for all activities but they were less enthusiastic during the discussion of Activity 3 and the introduction to Activities 6 and 7.

d. Do students develop a conceptual understanding of the quantum mechanics in the unit?

1. Students did develop a conceptual understanding of the quantum mechanics in the unit.

The students' perception of learning matches the actual learning observed. During the interview, the students were asked what they learned that day in class. For all schools, the students accurately described the concept for the activity that they had completed that day. To determine if they understood the concept, the Student Questionnaire posed an open-ended question about learning, and in response students described learning about light sources, energy, spectra and energy diagrams. In addition, students were asked to complete on that topic, a Likert scale from 1 to 5 (1 being "definitely false" and 5 being "definitely true"). Average values for the questions using the Likert scale ranged from 3.49 to 4.24 indicating the student perception of learning a concept is between "neutral" and "true." The lowest average addressed the usefulness of the energy diagram in representing the atom. The highest average (4.24) showed that students rated as "true" the item concerning understanding the difference between LEDs and other light sources.

The quantitative analysis of student learning using the pre/post test scores discloses that significant learning occurred. All students who completed the post-test achieved an increase in the score. The average mean score for all the schools individually increased. School B had the lowest increase of 9.1 points while the highest score was 31.8 for School A. The average mean score for all schools combined increased by 15 points. The calculated t-scores for a two-tailed test using a probability of 0.05 show that all schools individually and combined have scores above the critical value. The value of r for the effect size is above 0.371 which is a large effect size which for all schools. Scores indicates that student learning was significant.

2. Students completing the fewest number of activities did not learn the concepts as well as those who completed more of the activities.

Another factor that may have affected the level of learning is the number of activities in the *Solids & Light* unit that were completed by the students**.** *Visual Quantum Mechanics* follows the learning cycle stages of exploration, concept introduction, and concept applications as shown in Data Table 3.1. Activities 1-6 complete one cycle. Activities 7-12 return to concept introduction and complete a second cycle. Teacher A completed 6 activities or one cycle. His students' post- test scores showed the largest increase in the mean score. The effect size for this group of students was the largest at .97 which is a large effect. Effect size is influenced by the number in the sample and there were only 6 students in this group. Teacher B finished 4 activities so the students did not complete the learning cycle. Scores for this school were the lowest for the gains in the mean, the effect size and the t-test. There were only 2 students in the class at School C so statistical calculations were not possible but the increase in the mean score was 14 points. These students completed 5 of the activities which is a complete cycle because Activity 5 is an application. The highest t-score value was calculated for School D which has the largest sample size. The effect size for this school was the second highest at .79 which is a large effect. These students finished 10 activities in the *Solids & Light* unit which is two cycles because Activities 11 and 12 are optional activities.

Limitations of the Study

Four limitations have been identified:

1. The participants were teachers who volunteered to be part of the study after the professional develop provided by QuarkNet. For this reason, teacher differences were not controlled.
2. The researcher is a member of the QuarkNet group which may have influenced her interpretations of the data.
3. The researcher used the *Solids & Light* program in her classroom prior to the 2007 summer institute. This may have influenced her interpretations of the data.
4. Research results, interpretations and conclusions are limited to the teachers and students involved in the study. The researcher does not intend to generalize the results beyond these teachers and students. However, readers may determine the transferability of these findings to their own environment.
5. This study is not an evaluation that compares *Solids & Light* to another curriculum as there are limited curricular resources for this content making comparisons challenging.

Discussion

There are several circumstances similar to all of the observed schools that may have affected the implementation of *Solids & Light*. Time was an issue for the teachers on multiple levels. The four teachers who participated in the observational study have multiple class preparations. Teachers A and B were also teaching chemistry. Teacher C was teaching physical science, trigonometry and calculus. Teacher D was teaching foundations of physics. It is difficult to find time to prepare new materials for students when trying to complete multiple preparations. Finding the time to implement the program was a concern for the teachers who attended the summer institute. One teacher commented in the journal entries that the material was interesting but he/she was not sure about the amount of time needed for the program.

There also was a time-related concern for where in the school year the unit should be taught as well as how to add this information without deleting concepts that are in the tested standards. On the email survey, teachers who did not implement *Solids & Light* choose "doesn't fit into my district curriculum" as a reason. Since most curricula are set to reflect the tested standards, the perception of the teachers is that the program does not teach the tested standards. The majority of the teachers who actually found the time to implement the *Solids & Light* unit became part of the observational study. Three of the four teachers in the observational study stated in the final interview that the state standards did not influence their use of *Solids & Light* because the students were seniors who had already taken the state assessment. The fourth teacher felt that there are important standards taught by this unit and he aligned the unit with the standards for his professional development presentation.

Although there are tested standards in the unit, the concepts for these are generally found at the end of the physics textbooks and teachers who follow the textbook generally do not have the time to reach those chapters. For all teachers who participated in the observational study, *Solids & Light* was the last unit taught at the end of the school year.

Time also was an issue for the students because of approaching deadlines for projects and finals. The majority of the students in the study were seniors. In this situation, most students are not as motivated to learn. Only one of the schools (School A) used the post-test as a class grade. If students' perceived that the test would not influence their grades, they may have been less motivated to learn.

Classroom discussions were both open-ended and close-ended. The *VQM* program asks questions that describe data which is on the closed end of the continuum and that compares or interprets data which is on the open end of the continuum. When checking for student understanding it also is important to be sure that they know the appropriate vocabulary. A close-ended question such as, “What is a photon?” is a valid question in this unit. Making sure that the proper connections are being made with a question such as, “What color is associated with an eV value of 2.4?” is valid as well. If students cannot answer these questions, then teachers must elaborate and ask leading questions to get them to the point of understanding the activity.

Less student motivation may also have affected the quality of the whole class discussions. Teacher A used both open-ended and close-ended questions on Activity 1. The students answered all questions but the teacher almost always elaborated. During the discussion from Activity 2, there were two questions that the students did not respond to which caused the teacher to give the answers. The students answered several additional questions which were followed by teacher elaboration. The discussion during Activity 3 was very short but students asked several questions showing more interest. Students answered all questions asked during the Activity 4 discussion followed by teacher elaboration. The amount of teacher elaboration indicates that students gave short or incomplete answers which in turn, may indicate low motivation.

Motivation for the students in School B appears to be at a lower level than School A. During Activity 2, the number of questions asked by the teacher as she leads the students through the activity, for the two hours combined, was more than 50 questions. Less than 20 of the questions were answered by the students. Observations indicate that the teacher gave the answers when the students did not respond. A short discussion occurred during Activity 3 and students answered all of the close-ended questions. Activity 4 did not have a class discussion. With only two students in School C, discussion was more similar to small group rather than whole class discussion.

Most of the class discussion at School D occurred during the “Do Now” activity at the beginning of each class period. Students answered the questions and the teacher elaborated as well. During Activity 2, the students were asked to predict a graph. Students did not want to volunteer to draw their graphs on the board. After Teacher D drew a student graph on the board, it was easier to get a second student volunteer to draw on the board. A small number of student volunteers may indicate lower motivation or lack of self confidence.

Implications for Professional Development

High quality professional development provides teachers with new skills and knowledge that enables them to produce an environment conducive to student learning (Gess-Newsome, 2001). New skills and knowledge generally requires a change in what teachers believe and what they do (Fullan 2001). Fullan refers to these changes in curriculum materials, instructional strategies, or beliefs about teaching as the implementation process (Fullan, 2001). Future professional development should consider addressing several strategies that will aid the implementation of the *VQM* program; alignment of the program with the science standards, emphasis of the learning cycle, and implementation strategies.

Aligning the program with state or national science standards emphasizes that the program is important and has meaning. A characteristic of change is need. Teachers must believe that a new program meets the needs of the students (Fullan, 2001). Teachers in the study expressed concern that there was no alignment to the standards, but Teacher A showed the alignment in his workshop. The first state and national standard addressed in *Solids & Light* is an understanding of scientific inquiry as the students engage in investigations and use technological tools. The second state and national standard attended to in the program is the understanding of the structure of atoms, compounds, reactions and interactions of energy and matter. Concepts included in this standard were states and properties of matter, the law of conservation of mass and energy, the laws of thermodynamics and electromagnetic waves. The third state and national standard addressed involves understanding energy in the earth system. This standard involves the organization and development of the universe. The fourth state and national standard attended to in the program focuses on understanding the relationship between science and technology in the application of science for functional purposes. The last state and national standard addressed involves the nature of scientific knowledge, the use of models, and a historical perspective of science. Professional development should emphasize these standards which the *Solids & Light* unit addresses so that teachers will see the program as a way to teach concepts that they already feel must be taught to enable students to be successful on the state assessment.

This emphasis also will illustrate that modern physics concepts do not have to be the last unit in the year even though they are at the end of the textbook. These concepts are connected to concepts that are taught throughout the year. Instead of leaving them for last, QuarkNet is trying to encourage teachers to incorporate modern physics into other units all year long. The professional development should provide instructional strategies that can be used for this purpose.

Professional development also should emphasize the learning cycle because it is a vital component of *VQM* as well as inquiry learning. Data from the study shows that learning is more significant if students complete the cycle. Teachers need to know where the activities fit into the cycle, so that they will understand when the cycle is complete, and what affect a completed learning cycle has on student learning. As a result, teachers also need to complete the learning cycle themselves by completing all of the activities in the proper order. Teachers need an understanding of the overall structure of inquiry, how the parts of the cycle build upon one another, how this affects the students' use of the materials and classroom discussions (Zubrowski, 2007).

Change also requires clarity. To affect change, teachers need to know what to do differently. Goals should be specifically stated and specific means of implementation should be clear (Fullan, 2001). Professional development should include implementation strategies that will guide the teachers in what to do in the classroom. Goals for *VQM* should include the benefits to student learning such as its alignment with the state and national standards and emphasis on the learning cycle as a component of inquiry learning. Implementation strategies also should include a discussion of the challenges that the teachers will face as they implement the program. Time has already been discussed as an issue in implementation. Providing participants an opportunity to collaboratively discuss where the program fits into the curriculum and how to make room for the program within the curriculum being taught will enhance the clarity of the change process. Teachers also need to be prepared for the additional preparation time required before beginning the unit with the students. Teachers may need to do more content reading to feel comfortable with the concepts or may want to prepare a power point presentation for the student to reinforce the concepts. For inquiry to be done effectively, the needed materials and practical structures must available (Zubrowski, 2007). Arrangements will need to be made for the lab materials particularly if they need to be purchased, borrowed, shared or improvised from current lab equipment. Planning also is required for access to computers and making sure that the VQM program is properly down-loaded on the computers. Providing time during the professional development to consider how these challenges will be addressed will enhance the implementation process during the school year.

All of these challenges can be overcome with the proper support. A third characteristic of change affecting implementation is quality and practicality which addresses having a program with high quality and the necessary resources. An infrastructure of pressure and interactive support encourages change

(Fullan, 2001). *VQM* is a high quality program that provides many resources. Professional development should include a greater emphasis on collaboration and strategies to encourage teachers to use the support system more effectively. Long-term collaboration may provide the pressure that teachers need to keep moving forward with the implementation of the program. The teachers who participated in the observational study were all lead teachers. They participated in collaboration during conference calls and were expected to direct additional professional development. This provided the pressure needed to complete implementation during the 2007-2008 school year.

Recommendations for Future Research

There are three suggestions for future research:

1. Repeat this investigation using a different unit in the *Visual Quantum Mechanics* program.
2. Repeat this investigation after changing some of the strategies in the professional development:
    a. Be sure to include time to do Activities 7-12.
    b. Place more emphasis on the importance of the class discussions.
    c. Place more emphasis on the importance of completing an entire learning cycle to enhance student learning.
    d. Emphasize the connections between the concepts taught by the program and the state science standards.
3. Use a larger sample, to be able to generalize the results to a larger population.
4. Compare *Solids & Light* to another unit that teaches the same objectives using different instructional methodologies.
5. Repeat this investigation using different tools for assessing student learning that might include more open-ended questions, more frequent testing, or an application project.

Final Thoughts

The purpose of the *Visual Quantum Mechanics* program is to explore quantum principles using the activity-based instructional approach of the learning cycle (Escalada, 1997). The learning cycle has three phases; exploration, concept introduction, and concept application (Karplus, 1977). The exploration stage allows students to access their prior knowledge as they explore the environment. In the *Solids and Light* unit, exploration occurs with the hands-on activities involving the incandescent light bulb and the LED. After that there is concept introduction as the students complete the energy diagrams, and particularly during the computer simulations. Finally, this is followed by the application which determines star composition and finding an Earth-like planet. Attaching new information to prior knowledge is an important principle in learning theory (Bradsford et al., 2000).

Teachers who understand learning theory will use instructional strategies that are most effective (McCombs and Miller, 2007). Instructional strategies are the methods in which a teacher uses materials, media, setting and behaviors to generate a classroom environment that fosters learning. An effective teacher uses a multitude of instructional strategies because no single teaching strategy works effectively in every situation (Danielson, 2007, Marzano, Pickering, and Pollock, 2001, and Stronge, 2007). The instructional strategies used in combination with *Solids & Light* included whole class discussion and small group work during the hands-on activities and computer simulations. During the labs and simulations the teacher became a facilitator of learning as the students became active learners. The discussion advocated by *VQM* includes compare and contrast questions about data. Comparing and contrasting is on Marzano's list of strategies that affects student achievement (Marzano, 2003). The result of the instructional strategies was that students were attentive during lab. Although students were less attentive during the discussion, lectures and videos, there was significant learning even in the school that completed only four of the *Solids & Light* activities.

Teachers who strive to improve their skills in teaching, such as instructional strategies, participate in professional development. High quality professional development containing both content and pedagogy, includes modeling for the teachers the learning methods to be used by students and spreading the teachers' learning over time so that they can assimilate the information, Teachers can implement these methods with students, and then reflect and collaborate within a supportive system (Garet, et al, 1999). The QuarkNet summer institute provided both content and pedagogy within the *VQM* program which includes strategies, resources and materials that teachers need for implementation and assessment. The content was quantum physics and the pedagogy was an experience in inquiry methodology. It also provided time for the institute participants to "do" the activities as the students would. Those teachers that volunteered to be lead teachers received addition support with the workshops that they conducted.

QuarkNet is providing high quality professional development to physics teachers across the state of Kansas. As a result, students are learning. There is ample support for those that desire to take advantage of it. All QuarkNet teachers are invited to attend meetings that occur twice a year for further collaboration in many topics including the *VQM* program. They can ask for help with the implementation (as simple as a phone call to KSU) and they can borrow equipment as well. It might encourage more teachers to use the *Solids & Light* unit if the KSU program would find it possible to expand and place more emphasis on Activities 7-12, provide a correlation between the objectives and the state science standards, and schedule time in the meetings that is formally reserved for discussion of the implementation of the *VQM* program for those who are using it in their classrooms.

As a member of QuarkNet, the researcher is a participant observer who directly benefits from this study. *Visual Quantum Mechanics* is a high quality program. The researcher has attended several professional development opportunities that described the characteristics of the program. The instructional strategies that are advocated by *VQM* have a positive affect on student learning. As a physics instructor, the researcher has been motivated by the results of this study to use *Solids & Light* more effectively with her students. As with the teachers in the observational study, the researcher has not completed the entire program with her classes and has not always used the whole class discussion as recommended in the teacher guide. Her goal as an instructor is to complete the entire program and use more whole class discussion with her students. In addition, exploring other units within the program could provide the opportunity to address other concepts using inquiry-based learning.

As a QuarkNet Teaching and Learning Fellow, the researcher has provided professional development opportunities to physics teachers with an inquiry learning theme. QuarkNet groups in Baltimore, MA and Dallas, TX were invited to experience *Solids & Light* last summer. As a result of this study, the researcher will include the correlation between the National Science Standards and the objectives of the *VQM* program as part of her presentation. Whole group discussions within the professional development will not only include the data comparisons as the teacher guide suggests, but also the importance of having the discussions with the physics students in the classroom.

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Appendix A - Permission Letters

Potential Study Participant Letter

Dear Potential Study Participant:

Last summer you attended a QuarkNet summer institute where you received training to use the *Visual Quantum Mechanics* unit called *Solids & Light*. You were also given the opportunity to become a lead teacher for the program. As lead teacher you would agree to implement the program in your classroom and conduct professional development for additional interested teachers.

A study is being done to determine the affect of the professional development in July on the implementation of the program and how the implementation affects student learning. You do not have to be a lead teacher to participate in this evaluation. If you agree to participate in the evaluation, you would be asked to complete three questionnaires and two interviews. You would also be asked to videotape your classroom as the *Solids & Light* program is implemented. A researcher will make a one day observation of your classroom.

Students in your classroom will be asked to complete a laboratory environment survey, two questionnaires and a pre-test and post-test. The researcher may randomly choose several students to interview.

I hope that you will be interested in participating in the evaluation of *Solids & Light* and that I will hear from you soon. If you have any questions, please don't hesitate to contact me for assistance.

Sincerely,

Laurie Cleavinger,

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 I may discontinue participation at any time.

If I have any questions about the rationale or method of this study, I understand that I may contact Laurie Cleavinger via email (frogteach@hotmail.com), phone (913-727-7477), or voicemail or fax (913-796-6124).

If I have questions about the rights of subjects in this study or about the manner in which the study is conducted, I may Rick Scheidt, Chair, Committee on Research Involving Human Subjects, 103 Fairchild Hall, Kansas State University, Manhattan, KS 66506, at (785-532-3224).

Printed Name ____________________________________ Date _________________

Signature _______________________________________

Anticipated Dates of Field Test(s) _______________________

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

____

____

Total Number of students in combined physics classes ________________

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

Request to Observe Classroom Letter: 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* program. The Kansas State University Physics Education group has developed 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.

Visual Quantum Mechanics began in 1995. It was written as an activity-based instruction approach of the learning cycle. In the *Solids & Light* unit, students explore the electrical and spectral properties of LED's and incandescent lights as they relate to quantum principles. 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.

Mr/Ms/Mrs attended a week of professional development last summer at Kansas State University sponsored by the QuarkNet group during which time he/she received training on the use of this program. We are very excited about Mr/Ms/Mrs implementing *Solids & Light* 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.

I am asking Mr/Ms/Mrs and his/her students to complete questionnaires that will provide me valuable feedback on the effectiveness of professional development on the implementation of the program and the effect of the implementation on student learning. 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 would like to seek your approval to observe first-hand the implementation of the unit *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 doing this for my own personal dissertation research. The results of this evaluation will help me determine the effectiveness of the professional development and implementation on student learning.

Mr/Ms/Mrs has already agreed for this observation to take place and I have sent him/her 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 other identifying features will not be linked with the results of this study.

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 one short survey and a pre-test over the objectives in the unit to his/her students.

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 feedback on the materials in the unit. In addition, I will ask, Mr/Ms/Mrs to administer a post-test that will be used to determine student learning.

I am excited about this opportunity and believe that your students as well as Mr/Ms/Mrs will benefit from this learning experience. Your school is very fortunate to have teachers such as Mr/Ms/Mrs who are willing to implement new teaching strategies.

I have enclosed an approval form for you to sign that grants me 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,

Laurie Cleavinger

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 publication about this study. In addition, I understand the name 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 Laurie Cleavinger via email (frogteach@hotmail.com), phone (913-727-6477) or voicemail or fax (913-796-6124)

If I have questions about the rights of subjects in this study or about the manner in which the study is conducted, I may Rick Scheidt, Chair, Committee on Research Involving Human Subjects, 103 Fairchild Hall, Kansas State University, Manhattan, KS 66506, at (785-532-3224).

Science Chair's/Administrator's Printed Name: _______________________________

Administrator's Official Title: ____

Science Chair's/Administrator's Signature: ___________________________________
Date: _______________

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

Request to Observe Students Letter: Parents

Dear Parent,

This letter is to inform you that the physics instructors, Mr/Ms/Mrs, is implementing a set of instructional materials that has been developed for the *Visual Quantum Mechanics* program. The Kansas State University Physics Education group has developed materials for this project to teach quantum physics to high school. 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.

Mr/Ms/Mrs attended a week of professional development last summer at Kansas State University sponsored by the QuarkNet group during which time he/she received training on the use of this program. We are very excited about Mr/Ms/Mrs implementing *Solids and Light* 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.

I am asking Mr/Ms/Mrs and his/her students to complete questionnaires that will provide me valuable feedback on the effectiveness of professional development on the implementation of the program and the effect of the implementation on student learning. 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 will be observing Mr/Ms/Mrs's physics class.

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 doing this for my own personal dissertation research. The results of this evaluation will help me determine the effectiveness of the professional development and implementation on student learning.

Mr/Ms/Mrs has already agreed for this observation to take place. 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 other identifying features will not be linked with the results of this study.

I have enclosed an approval form for you to sign that grants me 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,
Laurie Cleavinger

Cc: Mr/Ms/Mr

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 Laurie Cleavinger via email (frogteach@hotmail.com), phone (913-727-6477) or voicemail or fax (913-796-6124).

If I have questions about the rights of subjects in this study or about the manner in which the study is conducted, I may Rick Scheidt, Chair, Committee on Research Involving Human Subjects, 103 Fairchild Hall, Kansas State University, Manhattan, KS 66506, at (785-532-3224).

Student's Printed Name: ____________________________________

Student's Signature: ____ Date: __________

Parent's Printed Name: _____________________________________

Parent's Signature: ____ Date: __________

Dear Parent,

Thank you for allowing your child to participate in the study of the Solids & Light unit. I am returning a photocopy of your consent form for your records. This verifies that there are no risks anticipated for any of the participants.

If you have any questions or concerns with the study or the videotaping, please contact Laurie Cleavinger at the above email address.

Sincerely,

Laurie Cleavinger

Letter of Appreciation

Dear Mr/Ms/Mrs and Physics Students,

I would like to take this opportunity to thank you and your students for participating in the study of *Solids & Light* and for allowing an observer to monitor the implementation of the unit in your physics classroom at your school. The feedback that I have obtained from classrooms such as yours provide invaluable suggestions and recommendations for further professional development opportunities that will increase the effectiveness of the program in motivating students, helping them to make observations, and developing student conceptual understanding. Most importantly, by studying the implementation of *Visual Quantum Mechanics* in an actual high school physics classroom after the teacher has participated in a professional development institute, we can determine what about this approach "works" and what about this approach does not "work." Thus, you and your students have provided a valuable service.

I believe that you should be commended and applauded for your efforts to participate in professional development and to introduce quantum principles to your students by implementing the *Solids & Light* unit. 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 you, who are willing to take risks in trying something new, make physics exciting and relevant to their students.

Your students, their parents, 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 make more relevant to the students' lives. Thank you again for your participation and for allowing me to be a part of the wonderful learning environment that exists at _____ High School.

Sincerely,

Laurie

Cc: Administrator

Appendix B - Research Tools

QuarkNet Summer Institute Evaluation Form

1. Give your opinion about the program with regard to each of the following statements: (*Circle one on each line*.)

		Strongly Agree	Agree	Disagree	Strongly Disagree	Not Applicable
a.	The program staff responded effectively to my questions	1	2	3	4	N/A
b.	The materials that were provided will be of use in the classroom	1	2	3	4	N/A
c.	I feel confident to implement VQM in my classroom	1	2	3	4	N/A
d.	I understand the roles discipline other than mine play in creating VQM	1	2	3	4	N/A
e.	QuarkNet expectations for me were made clear	1	2	3	4	N/A
f.	School year expectations for my group were made clear	1	2	3	4	N/A
g.	I had significant opportunity to interact with teachers in my neighborhood group	1	2	3	4	N/A
h.	Opportunity to interact with teachers in my discipline was helpful.	1	2	3	4	N/A

i. I would like QuarkNet to address the following topic(s) during the fall meetings, and/or indicate what is still not clear. What questions do you have?

2. Please list the three most important things you learned from this Institute.

QuarkNet Email Survey for Institute Participants

Please answer the following questions and return by email.

1. Did you use the *Solids and Light* program in your classroom this year?
    a. _____ Yes (Please proceed to question #2).
    b. _____ No (Please proceed to question #7).
2. Did you volunteer to be a lead teacher?
    a. _____ Yes
    b. _____ No
3. Did you volunteer to be in the program evaluation?
    a. _____ Yes – Thank you for your answers. You are finished with the survey.
    b. _____ No
4. Did you use all of the activities in the *Solids and Light* program?
    a. _____ Yes
    b. _____ No
        i. Please check all reasons that apply to you
            1. _____ Not enough time.
            2. _____ Some activities did not apply to my curriculum.
            3. _____ Some activities did not align with the state standards
            4. _____ I didn't understand some of the activities
            5. _____ I didn't have the necessary equipment
        ii. Please list the number of the activities that you did not use.
            1. ____
5. What was the most helpful part of the *VQM* training during July 2007?
6. What information would you like to see added to future *VQM* training sessions?
7. Please rank the reasons that you chose not to use *Solids and Light* in your classroom. 1 = most important
    a. _____ doesn't align with state standards
    b. _____ doesn't fit into my district curriculum
    c. _____ lack of access to hands-on equipment
    d. _____ student prerequisites were not met
    e. _____ cost of the program
    f. _____ limited access to computers
    g. _____ limited time to learn the program
    h. _____ implementation time is too long
    i. _____ not enough time in the school year
    j. _____ initial training was not adequate
    k. _____ other: ___________________________

THANK YOU FOR YOUR TIME. THE INFORMATION IS GREATLY APPRECIATED!!

Information for *Solids & Light* Implementers

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___________________________ email__________________________________
(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	African-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 ☐

Total number of students in the school: ____ Approximate percentage of males ____ Females ____

Approximate percentage of

White ____ African-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

Inquiry Learning Activities

To what extent do you use inquiry activities in your physics teaching? (Please circle all that apply)

1. I almost never use inquiry activities in my classroom……………… ……………….1
2. I seldom use inquiry activities in my classroom ……………………………………...2
3. I sometimes use inquiry activities in my classroom …………………………………..3
4. I often use inquiry activities in my classroom ………………………………………..4
5. I very often use inquiry activities in my classroom……………………………………5
    a. Activities are mostly guided inquiry ……………….……………….….a
    b. Activities are sometimes guided and sometimes open-ended…………..b
    c. Activities are mostly open-ended inquiry………………………………c
    d. Other uses (please specify) _____________________________________d

Classroom Observation Protocol

Observer(s) _________________________ Date of Observation ________________

Instructor __________________________ Time of Observation _______________

Location ____

Class/Level ____________________________ Start ________ End ___________

Students

Number of students present______________

Number of students normally in class______

Gender of students present: males _______ females ___________

Number of minorities present____________

Age range of students: ___________

Physical Environment:

What is the physical space of the class like? How are the tables set up? What resources are available? Is student work on the boards? If so, what is the nature of the work?

<u>Lesson</u>

1. Unit of Solids & Light:

2. Teaching Strategy predominant in that unit:

3. Intended outcomes

4. Describe how lesson was introduced, then indicate overall emphasis of the introduction.
<u>Description:</u>

5. What happens at the end of the class? Is there closure?
<u>Brief Description:</u>

<u>6. Introduction emphasis</u>: (*Indicate all that apply*)

○ Provide overview

○ Explain activity

○ Relate this lesson/activity to previous lessons/activities

○ Provide rationale for doing the activity

○ Assess prior knowledge

○ Other (describe):

7. What <u>modes of instruction</u> were used during this lesson? (*Indicate all that apply.*)

○ Lecture

○ Demonstration by instructor

○ Whole class discussion

○ Peer Instruction

○ Review homework

○ Students solving (addressing) problems or questions in small groups

○ Students working in groups to answer teacher-posed problem; reporting out

○ Students solving (addressing) problems or questions independently

○ Students developing questions or problems

○ Recitation/drill/practice

○ Students working on computer

○ Students using hands-on activity (red bullets are added)

○ Other (describe):

8. What <u>activities did students engage in</u> during this lesson? (*Indicate all that apply.*)

○ Listen and take notes

○ Complete worksheets or do practice problems in class

○ Give presentations

○ Write in journals or logs

○ Take a test/quiz/exam

○ Self-assessment

○ Read a textbook, other book, article, or hand-out in class

○ Laboratory or hands-on activity

○ Develop laboratory investigations

○ Work on computer

○ Out-of-class activity (including fieldwork)

○ Other (describe):

9. What <u>materials were used</u> during this lesson? (*Indicate all that apply.*)

○ Assigned textbook for the class

○ Other textbook

○ Other book, hand-out, article (print reading materials)

○ Workbook or worksheets

○ Laboratory equipment (implements, instruments)

○ Manipulative (hands-on equipment)

○ Videos

○ Slide projector

○ Computers (word processing, spread sheets. databases, etc.)

○ Computer-based technologies (Internet, CD-ROM, microcomputer-based laboratories, etc.)

○ Test manual or commercially made test sheets

○ Overhead projector, LCD projector

○ Chalkboard, whiteboard

○ Demonstration models

○ Other (describe):

10. Make a tick mark for each observation of the most descriptive activity at the specified time. Record five observations per five-minute time interval.

Code	Students' specific behavior	5	10	15	20	25	30	35	40	45	50	Total
SS1	Listening to the instructor talk											
SS2	Listening to a student talk											
SS3	Interacting directly with instructor (responding to or asking questions of the instructor											
SS4	Discussing relevant class material with each other (Data/results, concepts, debating, asking questions)											
SS5	Reading class materials (handouts, notes papers, etc.)											
SS6	Engaging in minds-on activity (solving problems, reflecting on work, drawing conclusions)											
SS7	Transferring info to written form (filling out worksheets, taking notes, taking tests)											
SS8	Replicating science (following explicit procedures, verifying known phenomena, collecting data, hands-on activity)											
SS9	Practicing science (formulating questions to investigate, designing ways to answer questions)											
SS10	Working on computer for work processing											
SS11	Working on computer for simulations											
SS12	Undetermined (i.e. staring)											
SS13	disengaged											
SS14	Other:											

11. What <u>assessment strategies</u> were used during the lesson? (*Indicate all that apply.*)

○ Short-answer test or quiz

○ Essay-type test or quiz

○ Group quiz or test

○ Discussion responses

○ Recitation responses

○ Observations of group work (assessing students' understandings; facilitating)

○ Journals or log entries

○ Oral reports or presentations by students

○ Report out after group discussions

○ Peer review

○ Other (describe):

12. <u>Overall Emphasis</u>: (*Indicate all that apply.*)

	Major Emphasis	Minor Emphasis
○ Learn facts or definitions	______	______
○ Understand science concepts or principles	______	______
○ Assess prior knowledge	______	______
○ Learn real-world applications of science	______	______
○ Follow a written procedure to do an investigation	______	______
○ Design experiments to answer question(s)	______	______
○ Students do an investigation to answer their own questions	______	______
○ Collect data (e.g., observe, measure)	______	______
○ Interpret data (e.g., compare, estimate, recognize patterns)	______	______
○ Engage in thinking skills (e.g., predict, infer, evaluate)	______	______
○ Develop skills in working collaboratively	______	______
○ Develop communication skills (e.g., writing, giving presentations)	______	______
○ Work on a long-term project that incorporates many of the above	______	______
○ Other (describe):	______	______

13. Indicate the major ways students were structured and indicate *approximate* percent of time.

○ whole group; percent ________

○ individuals; percent _______

○ small groups (3-4 students); percent _________

○ pairs; percent __________

Typology: Inquiry-based Teaching and Learning

(***Fill out after the observation.***) Use operational definitions for typology.

Students:

look for correct answer	---	accept or revise their "hypothesis" based on evidence
do not reflect on others' ideas	---	reflect on others' comments/ideas
seek information to complete the assigned work	---	seek clarification of conceptual understanding

Evidence:

Teacher Role:

source of knowledge	---	facilitator
questions or comments seek memory/facts	---	questions or comments seek comprehension/ opinion

Evidence

Classroom Activities:

algorithms	---	heuristics

Evidence:

Emphasis:

abstract	---	connected to real-world

Evidence:

Instructional Strategies:

reflected content	---	balanced content and process
reflected individual achievement	---	reflected collaborative working relationships

Evidence:

For Discussions:

Amount of time observed:
Percent of students contributing to the discussion:

closed questions	--	open-ended questions
teacher seeks facts	--	teacher seeks student understanding
students do not use evidence to support claims	--	students use evidence to support claims
teacher talks	--	students talk
students talk only to teacher	--	students talk to one another
teacher provides reasoning	--	teacher helps students reason through thinking process

Evidence:

For Laboratory/Hands-On/Fieldwork:

Amount of Time Observed: Activity number of *Solids & Light*:

Grouping (pairs, threes, fours):

Cooperative/collaborative (yes, no):

students follow a procedure to answer a question or conduct an investigation	--	students answer a question or solve a problem using open-ended instructions
students take measurement or determine facts to answer questions (one answer possible)	--	students collect and manipulate data in order to answer questions (several answers possible)

Evidence:

Evidence of student learning during observation:

Reflections and Interpretations

(***Fill this out as soon as possible after the observation.***)

1 - How effective was implementation of the *Solids & Light*, especially use of alternative strategies advocated in the *VQM* program?

2 - What didn't happen (e.g., students didn't grasp the idea of the lesson)?

3 - Alternative ways instructor might have handled the lesson/question/ situation:

4 - Characterize students and their attitudes toward the subject matter and the teacher:

5 - Note instances of inequity such as a group of students being neglected, needs of English Language Learners or other special needs students not being addressed, only a handful of students being called on during recitation/discussion.

6 - Notable non-verbal behavior (e.g., slouching, looking out the window):

7 - Surprises/concerns, especially related to the extent of inquiry-based teaching and learning:

OPERATIONAL DEFINITIONS FOR TYPOLOGY

The typology is meant to capture, in retrospect, the observer's overall interpretation of where the teacher's practice may fall on each of the continua. The items in the left column are generally more 'traditional' and the items in the right column generally reflect more inquiry. No value judgment of the teacher is intended. Value judgements should be left to REFLECTIONS AND INTERPRETATIONS. Each item is intended to refer to something that might be transferred from the teacher's participation in the program to their classroom practice. Place an 'x' on the spot you feel best indicates what you observe for that class/lesson. You might think of the line in terms of percent, e.g., if the teacher acts like a source of knowledge for 40% of the time and is a facilitator 60% of the time put the 'x' to the right of the half-way point toward 'facilitator'.

Write any explanatory notes in the margin or indicate "N/A" if the continuum is not applicable to the classroom you observed. For example, the continuum in the Discussion section, "teacher helps students reason through the thinking process --- teacher provides reasoning" is not applicable in cases where there is no attempt to bring students' understanding or thinking about a subject/idea to a higher level. In this case record both 'N/A' and a brief comment about the nature of the discussion.

Students:

- look for correct answer = students do an activity or engage in discussions and focus on "getting the correct answer" (as opposed to "seek truth").

  accept or revise their "hypotheses" based on evidence = students may have developed some ideas prior to the current lesson. Now, they use evidence, either direct or though a discussion, and revise or accept their idea based on that evidence. The key is that students show they are thinking about the subject/topic rather than perfunctorily doing activities, taking notes or whatever, almost waiting until class is over.

- do not reflect on others' ideas = students do not build on what other students say nor refer to what other students might be saying; neither do they act on other students' ideas and/or suggestions.

  reflect on others' comments/ideas = students relate to what others' say through discussion or taking some action. Students build on what other students say but may not directly acknowledge them by name.

- seek information to complete the assigned work = students may ask questions about procedure such as asking the teacher or other students if they should finish the exercise for homework, or, may ask direct questions about how to answer a particular question in order to complete an assigned task.

  seek clarification of conceptual understanding = students ask the teacher or other students for explanations and clarifications of the questions asked in order to better understand the content. During a discussion a student may relate an experience s/he has had related to the topic in order to fit this information into his or her conceptual understanding of the topic.

Teacher Role:

- source of knowledge = teacher is the "sage on the stage" and neither seeks nor acknowledges student input. The teacher may ask students questions but only in order for them to relate facts or content-specific information.

  facilitator = teacher seeks input from students and encourages students to explain, predict, describe, etc. in order to increase their and other students' understanding. The teacher will often seek a student's misunderstandings and ask other students to offer a better/different explanation, prediction, etc. versus "correcting" a student. In laboratory or hands-on activities, the teacher will offer suggestions and/or work with the students to find solutions or work out problems.

- questions/comments ask for memory/fact = teacher looks for the correct answer around a fact such as asking for a definition. The teacher generally asks short answer questions that require memory.

  questions ask for comprehension/opinion = teacher asks probing questions and/or encourages discussion which requires student understanding. (Understanding = the student can apply what they know to a new situation by explaining, giving examples, predicting, and interpreting.) The teacher generally asks questions that require processing, however, the processing may not be in the form of a direct question. Look for implicit and well as explicit questioning.

Classroom Activities:

- algorithms = procedural steps or formula to solve problems and/or answer questions. This is most often seen in mathematics classes where students are taught to use a specific procedure to solve mathematics problems. In science class it is often seen in 'cookbook' laboratory manuals.

  heuristics = use of overall strategies or plan to solve problems and/or answer questions. This can be seen wherever students are asked to use critical thinking skills. (Critical thinking skills include problem solving, evaluation, decision-making, deductive and inductive reasoning.)

Emphasis:

- abstract = the content may be of academic interest but is not directly related to a student's everyday experience. Students usually perceive the content as something they must learn, and may have to know to pass a test, but isn't anything they would have to deal with in their 'real-life.'
  (Note: it is students' perceptions that count, therefore, to make this entry, you have to talk with students or base your judgment on something said in class.)

  connected to real-world = the content is perceived as relevant to something in the students' lives or to the understanding of something in the real-world. It may also be related to something that exists in the real-world, but is not directly part of the students' experiences.

Instructional Strategies:

- reflected content = the instruction is directly related to content only not reflecting the process whereby that content originated nor how to investigate questions related to the content.

  balanced content and process = the instruction balances the content with the origins of how the content was discovered or came to be known and/or process of investigating questions about the content.

- reflected individual achievement = individuals learn the content and engage in any activities; may include competition among individuals.

  reflected collaborative working relationships = students work together in a collaborative atmosphere to investigate, discuss, explore, answer questions.

Discussions: note whether or not this is more like 'recitation' than 'discussion.'

- closed questions = no matter who talks with whom, the discussing group seeks to determine the right answer, which is usually a fact. (Note: the "questions" may be implicit. This continuum is meant to capture the overall tenor of the discussion as being closed or open.) A typical closed question is, "What is 4 x 4?", or "What are the temperature and moisture conditions that define a desert?"

open-ended questions = no matter who talks with whom, members of the discussing group are seeking possible explanations/causes/descriptions/ understandings. A typical open-ended question is, "What do you think might happen if...?", or "If you got a '4' for the answer and I got a '6', why might our answers be different?"

- teacher seeks facts = the teacher encourages students to determine 'the' answer to a question or 'the' solution to a problem.

  teacher seeks student understanding = the teacher seeks students' understandings and misunderstandings, often as a way to determine class, and individual progress (perhaps as a form of assessment).

- students do not use evidence to support claims = students give factual answers or read facts off a workbook or lab page without further explanation.

  students use evidence to support claims = students provide data or collaborating evidence to support what they are saying. For example they might say, "I saw that the longer the water was heated the higher the temperature got which explains that ..."

- teacher talks = amount of time teacher talks during the discussion.

  students talk = amount of time students talk during the discussion. (Note also the number of students who are doing the talking.)

- students talk only to teacher = the 'discussion' may be characterized as more of a recitation when the interaction is between teacher and students, however, the continuum suggests that there is probably some mixture among students talking with the teacher and talking to another.

  students address one another = students turn toward and talk with one another without the teacher as a mediator. (Note: this is to be taken literally. Students may refer to what one another has said without talking directly to that student. This kind of interaction is captured in another continuum.)

- teacher provides reasoning = teacher may help students understand a topic/principle/idea through providing them with the reasoning behind what they are telling students.

  teacher helps students reason through thinking process = teacher asks for students' reasoning, encouraging them to support and contradict one another through discussion. At both ends of this continuum, student understanding may reach a higher level, but this end of the continuum is intended to capture the constructivist approach whereby students are helped in their understandings starting from their own perspectives/observations.

For laboratory/Hands-on/Fieldwork

- students follow a procedure to answer a question or conduct an investigation = this refers to what educators often call "cookbook" investigations.

  students answer a question or solve a problem using open-ended instructions = this refers to anything that is more inquiry-oriented.

- students take measurements or determine facts to answer questions (one answer = the results of the investigation are a series of one right answers even though the students may be taking measurements and even collecting other data.

  students collect and manipulate data in order to answer questions (several possible answers) = there is no one answer but several answers that are appropriate because students are collecting and manipulating data related to a phenomena.

Interview Questions for Instructors After the First Observation

1. How typical was the instruction during the time observed? In what ways was it typical? In what ways was it different?

2. Did you accomplish what you had planned for today's class?

3. What are the next steps after what we've seen today?

4. What are the next steps after what we've seen today?

Interview Questions for Instructors after Completion of *Solids & Light* Unit

1. What has most influenced the way you teach (instructional strategies)? (e.g., the way others taught you, a pre-service education methods course)

2. Did the *VQM* training in July adequately prepare you to implement the program in your classroom? Explain.

3. In what ways has your instruction be changed by the professional development last summer? Please give specific examples of things you have done differently.

4. How did the Science Standards influence the way you implemented the *Visual Quantum Mechanics* materials?

5. If you have previously used modeling in your classroom, how did this effect the implementation of *Solids & Light*?

6. What did this program cost you in terms of time, money, materials, and etc.?

Instructor Questionnaire A

Solids & Light

Activities 1-6

Please complete this questionnaire and have the students complete the student version before moving to Activity #6.

1. What are the most important physics concepts that your students learned by doing Activities 1-6?

2. Did your students meet the prerequisites for these activities? If not, what skills were they lacking?

3. Did your students have any difficulties with the experiments or the concepts? If yes, please be specific.

4. For each activity provide the following information:

Activity	Time Required	What, if anything, did you omit from the activity?	What, if anything, did you add to the activity?
Activity 1 - Exploring LEDs and Lamps			
Activity 1 - Exploring Light Patterns			
Activity 3 - Introducing Energy Diagrams for Atoms			
Activity 4 - Understanding the Spectra Emitted by Gas Lamps			
Activity 5 - Applying Spectra and Energy Diagrams to Learn About Stars			
Activity 6 - Should Activity 6 be listed with the first 5 activities?			

Rate the overall effectiveness of the following components of Activities 1-5 in helping your students make observations and understand the objectives of the instructional units.

Question	Rating	Evidence
1-1 Describe and compare the characteristics of light emitted by light emitting diode (LEDs) with that of an incandescent lamp and Christmas lights.	Not effective Very effective 1 2 3 4 5	
1-2 State the turn-on (threshold) voltage for LEDs and incandescent lamps, including Christmas lights.	1 2 3 4 5	
1-3 Compare the threshold voltages for LEDs of different colors, and for incandescent lamps of different colors.	1 2 3 4 5	
1-4 Describe and compare the effect of changing the voltage applied to LEDs and incandescent lamps on the intensity and color of light emitted by these devices.	1 2 3 4 5	
2-1 Use a spectroscope to observe, describe, and identify the characteristic spectra emitted by gas lamps, incandescent lams, and LEDs.	1 2 3 4 5	
2-2 Observe the color changes of an incandescent lamp as the voltage is changed.	1 2 3 4 5	
2-3 Describe and differentiate between the energy of light related to color and that related to intensity.	1 2 3 4 5	
2-4 Present data for the spectra of the various devices.	1 2 3 4 5	
3-1 Sketch an energy level diagram for an atom.	1 2 3 4 5	
3-2 Understand how changes in an atom's energy are related to the emission of light.	1 2 3 4 5	
4-1 Using the Atomic Spectroscopy computer program to construct a possible set of allowed energies for an electron when given the spectral lines.	1 2 3 4 5	
4-2 Explain why gas spectra leads to the conclusion that the atom's electrons can have only certain values.	1 2 3 4 5	
5-1 Explain how absorption and emission spectra are related.	1 2 3 4 5	
5-2 Identify a set of absorption lines belonging to a particular element.	1 2 3 4 5	
5-3 Explain how scientists can determine the composition of objects like a star.	1 2 3 4 5	
6-1 Describe how absorption spectra can be used to identify gases in the atmosphere of a distant planet.	1 2 3 4 5	
6-2 Have a better understanding of the relation between absorption and emission spectra.	1 2 3 4 5	

Return these pages in the enclosed envelope to: Laurie Cleavinger
22110 McIntyre Rd
Leavenworth, KS 66048

If you have questions about any aspect of the project, you may use the address above. Your request will be forwarded to the appropriate person.

Thanks for your help!

Instructor Questionnaire B

Solids & Light

Activities 7-12

Please complete this questionnaire and have the students complete the student version at the end of the two-week unit.

1. What are the most important physics concepts that your students learned by doing Activities 6-11?

2. Did your students meet the prerequisites for these activities? If not, what skills were they lacking?

3. Did your students have any difficulties with the experiments or the concepts? If yes, please be specific.

4. For each activity provide the following information:

Activity	Time Required	What, if anything, did you omit from the activity?	What, if anything, did you add to the activity?
7. Using Gas Lamps to Understand LEDs			
8. Applying Energy Bands to Incandescent Lamps			
9. Creating an Energy Level for Model LEDs			
10. Appling Energy Level Models to LEDs			
11. Can Ohm's Law Explain Your Observations?			
12. Using LEDs to Measure Planck's Constant			

Rate the overall effectiveness of the following components of Activities 6-9 in helping your students make observations and understand the objectives of the instructional units.

Question	Rating	Comments
7-1 Describe why closely spaced energy levels are needed to explain the spectra of an LED.	Not effective Very effective 1 2 3 4 5	
7-2 Explain how the difference in energy between the upper set of energy levels and the lower set is related to the color of light emitted by an LED.	1 2 3 4 5	
7-3 Define the terms "valence band" and "conduction band".	1 2 3 4 5	
8-1 Describe how the energy bands in a solid lead to the creation of white light.	1 2 3 4 5	
7-2 Understand the roles of conduction and valence bands in a solid.	1 2 3 4 5	
9-1 Be familiar with the energy bands and gaps in LEDs.	1 2 3 4 5	
9-2 Understand the role of energy gaps in determining the threshold voltage of an LED.	1 2 3 4 5	
10-1 Explain the effect of an applied voltage upon the energy bands in LEDs.	1 2 3 4 5	
10-2 Understand how LEDs produce light.	1 2 3 4 5	
10-3 Explain why LEDs have the properties described in the prerequisites.	1 2 3 4 5	
11-1 Understand the limitations of Ohm's Law in explaining the I-V graphs of the incandescent lamp and the LED.	1 2 3 4 5	

5. If you did Activity 12 – Using LEDs to Measure Planck's Constant, which is an optional activity, what did it add to your student's understanding of quantum concepts?

Please include any additional comments which could help us improve activities 6-9.

Rate the overall effectiveness of the following components of Activities 6-9 in helping your students make observations and understand the objectives of the instructional units.

Question	Rating	Comments
7-1 Describe why closely spaced energy levels are needed to explain the spectra of an LED.	Not effective Very effective 1 2 3 4 5	
7-2 Explain how the difference in energy between the upper set of energy levels and the lower set is related to the color of light emitted by an LED.	1 2 3 4 5	
7-3 Define the terms “valence band” and “conduction band”.	1 2 3 4 5	
8-1 Describe how the energy bands in a solid lead to the creation of white light.	1 2 3 4 5	
7-2 Understand the roles of conduction and valence bands in a solid.	1 2 3 4 5	
9-1 Be familiar with the energy bands and gaps in LEDs.	1 2 3 4 5	
9-2 Understand the role of energy gaps in determining the threshold voltage of an LED.	1 2 3 4 5	
10-1 Explain the effect of an applied voltage upon the energy bands in LEDs.	1 2 3 4 5	
10-2 Understand how LEDs produce light.	1 2 3 4 5	
10-3 Explain why LEDs have the properties described in the prerequisites.	1 2 3 4 5	
11-1 Understand the limitations of Ohm’s Law in explaining the I-V graphs of the incandescent lamp and the LED.	1 2 3 4 5	

5. If you did Activity 12 – Using LEDs to Measure Planck’s Constant, which is an optional activity, what did it add to your student’s understanding of quantum concepts?

Please include any additional comments which could help us improve activities 6-9.

General questions about the entire unit.

1. Are you comfortable with the subject covered in this unit?

2. Where in your normal curriculum would you use this two-week unit? What would the students study before and after this unit?

3. Would you recommend this unit to other teachers? Why or why not?

4. What support materials (i.e. activity handouts, instructor manual, computer manual, equipment lists, etc…) were the most useful?

5. Which activities in the *VQM* training were most helpful?

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22110 McIntyre Rd
Leavenworth, KS 66048

If you have questions about any aspect of the project, you may use the address above. Your request will be forwarded to the appropriate person.

Thanks for your help!

Science Laboratory Environment Inventory (SLEI)

Class Actual Form

Read each of the 21 statements. For each statement, circle the number that best represents your experience in your current physics classroom using the following scale.

1. Almost never
2. Seldom
3. Sometimes
4. Often
5. Very Often

Remember that you are being asked how often (Almost Never, Seldom, Sometimes, Often, Very Often) that each of the following practices actually takes place in this laboratory class.		For Teacher's Use
1. There is opportunity for the class to pursue our own science interests in this laboratory class.	1 2 3 4 5	_____
2. What we do in our regular science class is unrelated to our laboratory work.	1 2 3 4 5	R _____
3. The laboratory is crowded when we are doing experiments.	1 2 3 4 5	R _____
4. In this laboratory class, we are required to design our own experiments to solve a given problem.	1 2 3 4 5	_____
5. The laboratory work is unrelated to the topics that we are studying in our science class.	1 2 3 4 5	R _____
6. The equipment and materials that we need for laboratory activities are readily available.	1 2 3 4 5	_____
7. In our laboratory sessions, different students collect different data for the same problem.	1 2 3 4 5	_____
8. The regular science class work is integrated with laboratory activities.	1 2 3 4 5	_____
9. We are ashamed of the appearance of this laboratory.	1 2 3 4 5	R _____
	1	
10. Students are allowed to go beyond the regular laboratory exercise and do some experimenting of our own.	1 2 3 4 5	_____
11. We use the theory from our regular science class sessions during laboratory activities.	1 2 3 4 5	_____
12. The laboratory equipment which we use is in poor working order.	1 2 3 4 5	R _____
13. In our laboratory sessions, different students do different experiments.	1 2 3 4 5	_____
14. The topics covered in regular science class work are quite different from topics with which we deal in laboratory sessions.	1 2 3 4 5	R _____
15. The laboratory is hot and stuffy when students are doing experiments.	1 2 3 4 5	R _____

16. In our laboratory sessions, the teacher decides the best way for us to carry out the laboratory experiments. 17. What we do in laboratory sessions helps us to understand the theory covered in regular science classes. 18. The laboratory is an attractive place for the class to work in.	1 2 3 4 5 1 2 3 4 5 1 2 3 4 5	R _____ _____ _____
19. Students decide the best way to proceed during laboratory experiments 20. The class laboratory work and regular science class work are unrelated. 21. Our laboratory has enough room for individual or group work.	1 2 3 4 5 1 2 3 4 5 1 2 3 4 5	_____ R _____ _____

Solids & Light Student Assessment

Name: ________________________ **Date:** _________

School: ______________________ **Instructor:** ______________________

Solids & Light
Student Assessment

General Directions: There are two parts to this assessment: a short answer and multiple-choice/short answer sections. Use the scale on the right to answer questions from both parts.

Range of Energies for Various Colors of Light (eV)

Infrared	< 1.6 eV
red	1.6 – 2.0
orange	2.0 – 2.1
yellow	2.1 – 2.3
green	2.3 – 2.6
blue	2.6 – 2.8
violet	2.8 – 3.1

Part I (Short Answer)

Directions: Answer the following questions with complete descriptions and sketches.

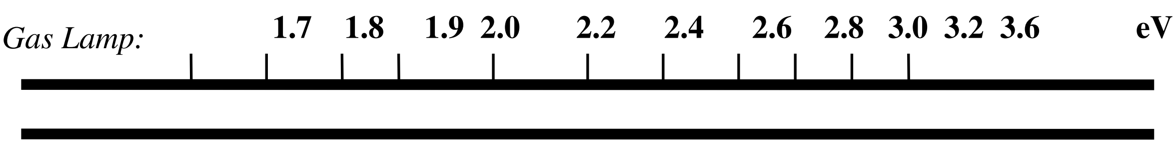
1. Describe how the LED and the incandescent lamp differ in terms of their:

(a) physical properties

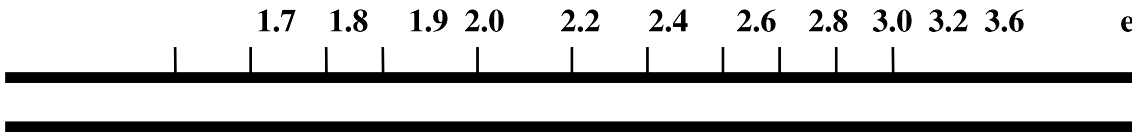
(b) electrical properties

2. Use the following scales to sketch the ***general*** features of the spectra emitted by a gas lamp, an incandescent lamp, and a blue LED.

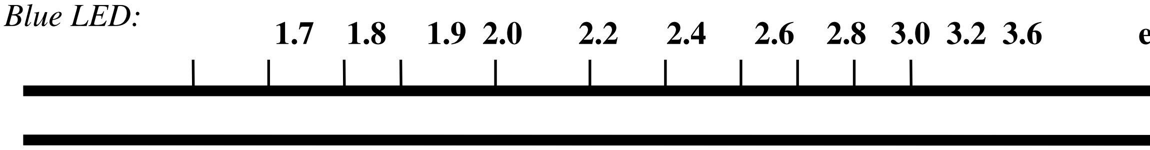
(a) *Gas Lamp:*



(b) *Incandescent Lamp:*



(c) *Blue LED:*

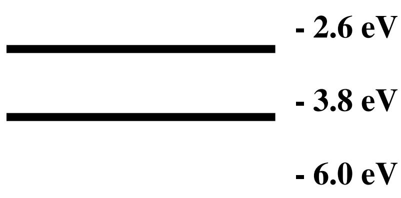


3. Draw and describe an energy diagram that would explain the above spectral properties for each device that you illustrated in the previous question. Label the components of each energy diagram. Describe any assumptions you have made

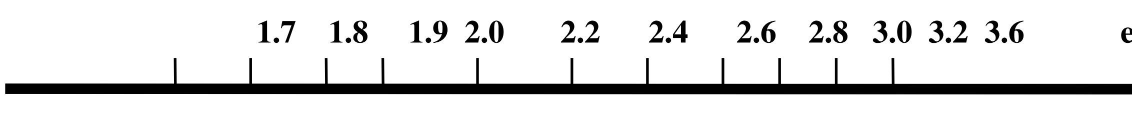
(a) *Gas Lamp* (b) *Incandescent Lamp* (c) *blue LED*

4. The energy level diagram below represents a possible set of energies for an atom.

(a) On the energy level diagram indicate the allowed transitions for an electron bound to this atom.



(b) Construct on the scale below the spectrum of light emitted by this atom represented by the above energy level diagram. Estimate the placement of any values that fall outside the scale.

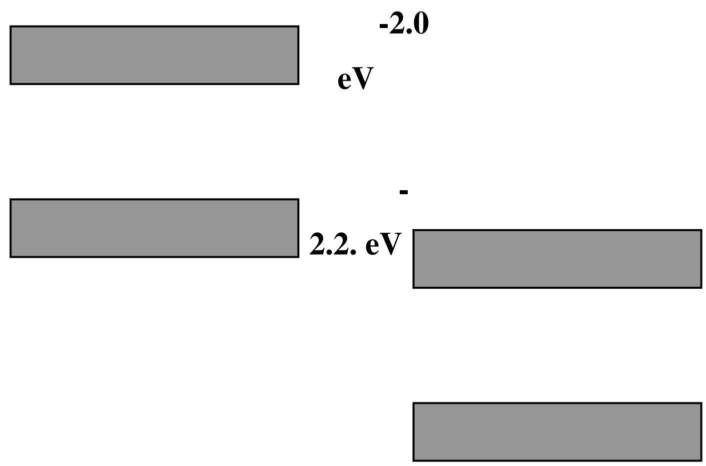


(c) **What, if any, parts of the resulting spectrum are in the visible spectrum? Identify the specific colors of light and their respective energies.**

(d) **What, if any, parts of the spectrum are in the infrared region?**

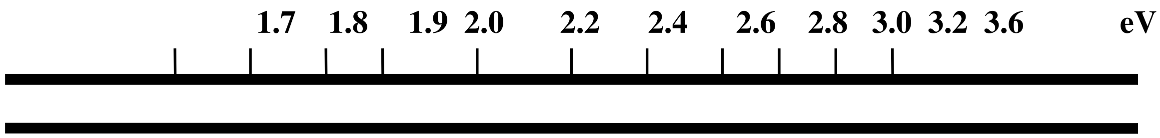
(e) **What, if any, parts of the spectrum are in the ultraviolet region?**

5. An LED is created with a material which has the energy bands and gaps shown below. The band gaps are shown for zero voltage applied to the LED.



(a) Explain, using the diagram above, the possible transitions for electrons in this material.

(b) Sketch and describe the spectrum of light emitted by this LED. Estimate the placement of any values that fall outside the scale.



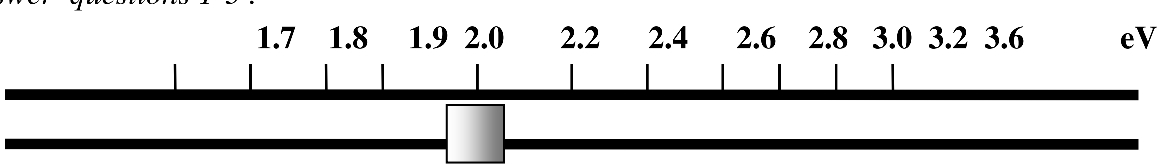
c) What is the threshold voltage of this LED?

d) Describe and explain the change in the energy bands for this LED as the voltage is increased from 0 Volts to 6 Volts.

e) Suppose you were asked to change one property in this solid to create an LED which emitted violet light. What property would you change? How would that result in violet being emitted?

Part II (Multiple Choice & Short Answer). For each question, select the best answer. In the space provided below the possible answers, explain your selection.

The diagram below illustrates the resulting spectrum emitted by a light source. Use the diagram to answer questions 1-3 .



1. The spectrum illustrated above is characteristic of what type of light source?

(a)light emitting diode (b) incandescent lamp (c) fluorescent lamp (d) hydrogen gas lamp

2. What color of light is emitted by this light source?

(a) green (b) yellow (c) blue (d) red (e) orange

3. What is the magnitude (in units of energy) of the energy gap for the material that makes up this light source?

(a) .10 eV (b) 2.25 eV (c) 2.15 eV (d) 2.2 eV

For questions 4 and 5, assume we have two LEDs – one LED emits a dim green light and the other LED emits a bright red light.

4. Which LED emits light with the greatest energy per photon?
   (a) the LED that emits red light.
   (b) the LED that emits green light.
   (c) neither, they both have the same energy per photon.

5. For the same two LEDs mentioned in the previous question, which LED emits the greatest number of photons?
   (a) the LED that emits red light.
   (b) the LED that emits green light.
   (c) neither, they both emit the same number of photons.

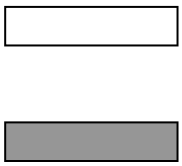
6. Which state of matter leads to the formation of allowed energy bands for its electrons which are bound to numerous closely packed atoms?
   (a) photons (b) liquids (c) solids (d) gases

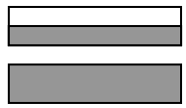
Use the following information to answer questions 7 and 8. An electron attached to an atom has a total energy of –6.5 eV. We then add 5.0 eV to this atom.

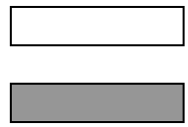
7. What will be the electron's new energy?
   (a) 11.5 eV (b) 1.5 eV (c) -1.5 eV (d) -6.5 eV (e) -11.5 eV

8. As a result of adding 5.0 eV to this atom, will this electron be attached to the atom?
   (a) Yes (b) No (c) Not enough information to answer the question.

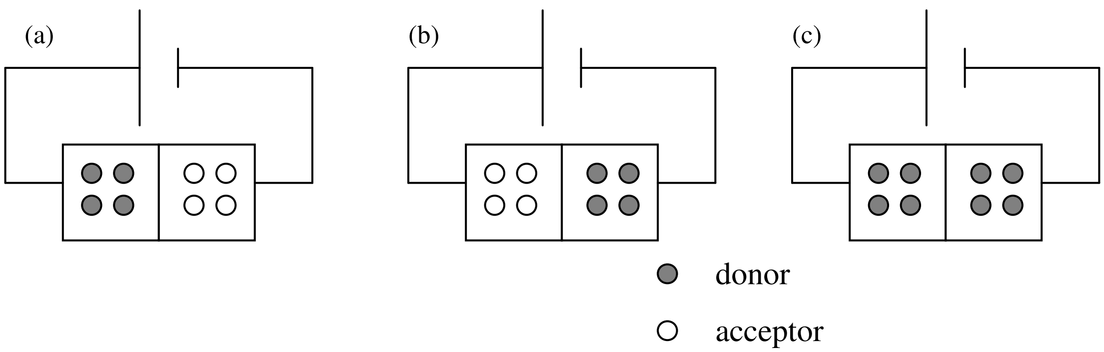
9. Which of the following energy band diagrams represents a semiconductor that has a small energy gap? Note that
the shaded regions represent the energies that electrons naturally possess in these materials (optional).

a. 

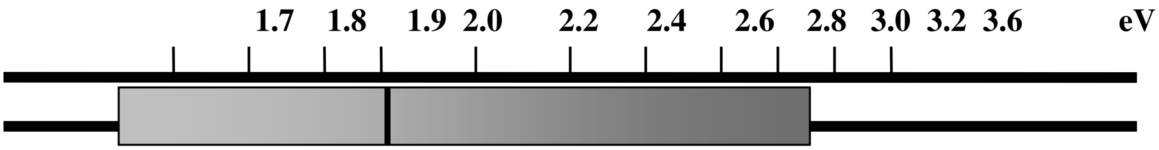
b. 

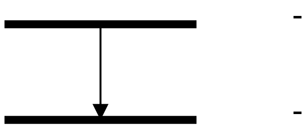
c. 

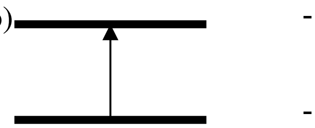
10. Which of the following semiconductor configurations in a circuit would result in the emission of light by an LED (optional)?

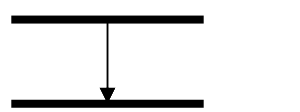


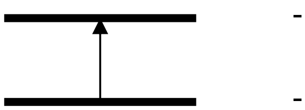
11. Which of the following energy diagrams explain the **absorption spectral line** of a certain gas as
illustrated below?

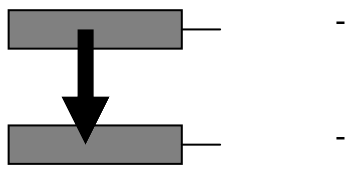


(a) 

(b) 

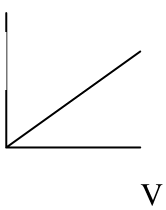
(c) 

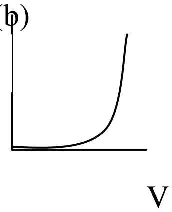
(d) 

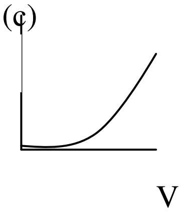
(e) 

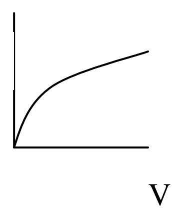
Question 12 is an optional question to be used only if your students completed the Activity 1 Optional homework assignment.

12. Which of the following graphs describes the graph of current (I) versus voltage (V) for a blue LED?

(a) 

(b) 

(c) 

(d) 

Student Interview Questions - Day of Classroom Observation

1. Which activity number were you working on today?

2. What was the activity about?

3. Did you have problems with any of today's activities? If so:

    a. Did you fix it yourself? How?
    b. Did you teacher help you?

4. Describe 2 things that you learned today.

5. What questions would you like to have answered for you?

Student Questionnaire

Solids & Light

Activities 1-6

1. Summarize in a few sentences what you have learned from completing Activities 1-6.

2. Are the activities that you did in this unit similar or different in nature from previous class activities? Explain.

3. Circle the responses that represent how you feel.

	DEFINITELY FALSE	FALSE	NEUTRAL	TRUE	DEFINITELY TRUE
The current-voltage investigations helped me understand how LEDs differ from other light sources.	1	2	3	4	5
Observing the spectra of gases Helped me understand how light is emitted by an atom.	1	2	3	4	5
The potential energy diagram is a useful representation of the atom.	1	2	3	4	5
The *Spectroscopy Lab Suite* program taught me how electrons are involved in the emission of light from an atom.	1	2	3	4	5
The *Spectroscopy Lab Suite* program helped me understand why light from one type of atom is different from light from another type of atom.	1	2	3	4	5
I can use the potential energy representation of an atom to explain the spectra that I observed.	1	2	3	4	5

Comments:

Thanks for your help!