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An Examination of Student Understanding of the Use of Models in Science and Conceptual Understanding of Electricity and Magnetism

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An Examination of Student Understanding of the Use of Models in Science and Conceptual Understanding of Electricity and Magnetism

A Dissertation

Submitted to the Graduate Faculty of the
University of New Orleans
in partial fulfillment of the
requirements for the degree of

Doctor of Philosophy
in
Curriculum and Instruction

by

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ABSTRACT

The purpose of this study is to inform instruction by increasing the body of knowledge regarding the relationship between college physics students' knowledge about models in science and their conceptual understanding with regard to electricity and magnetism. The data for this study was obtained through the administration of two instruments: Conceptual Survey of Electricity and Magnetism, a multiple choice assessment, and Student Understanding of Models in Science, a Likert-scale survey. Both traditional statistics and an innovative technique called Model Analysis were used to analyze the data.

Analysis of the data revealed that there is a relationship between student understanding of models in science and conceptual understanding of electricity and magnetism topics. However, the results of this study also suggest that without specific instruction on models in science, overall understanding of models in science does not improve after a traditional electricity and magnetism course. Additionally, this study demonstrated that not only does student conceptual understanding of electricity and magnetism topics improve after a traditionally taught electricity and magnetism course, but also, students demonstrate more sophistication in their understanding of some electricity and magnetism topics. In the latter case, students showed improvement in their application of the expert rather than the naïve or null model of electricity and magnetism topics.

Keywords: Conceptual Understanding, Education, Electricity, Magnetism, Model Analysis, Models, Physics, Science

CHAPTER 1 – STUDY OVERVIEW

Introduction

Beginning in the late 1970s and early 1980s, physics-education researchers uncovered two startling trends. First, despite the best efforts of their predecessors to improve instruction by improving traditional teaching methods (improving textbooks, demonstrations and lectures), little progress was made in improving student understanding of the fundamental concepts in physics (Arons, 1997). Second, with similar efforts to improve student understanding of the nature of science, results indicated that little improvement occurred (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Treagust, Chittleborough, & Mamiala, 2002).

In addition, the studies indicated a major problem hampering student success at developing a real understanding of physics topics: students possessed robust, difficult to change ideas about the topics. Also, researchers found that the correct knowledge they did possess was often fragmented. Terms used to describe this phenomenon are: naive ideas, alternative conceptions, pre-conceptions, or misconceptions. Furthermore, these studies pointed out that traditional instruction did little to change student views (Caramazza, McCloskey, & Green, 1981; Chi, Feltovich, & Glaser, 1981; Clement, 1982; diSessa, 1982; French, 1988; Goldberg & McDermott, 1986; Gunstone, 1987; Halloun & Hestenes, 1985a, 1985b; McCloskey, 1983; McCloskey, Caramazza, & Green, 1980; Schwartz, B. B., 1990; Thacker, Kim, Trefz, & Lea, 1994; Tobias & Hake, 1988; Trowbridge & McDermott, 1980a, 1980b; White, 1983).

At the same time, researchers in various fields of education and cognitive science began to realize that in order to improve science education, the purpose and focus of science education had to change. The push to move away from memorization and toward improved conceptual understanding began. Scientists and educators wanted the purpose of science education to become much more than memorizing a series of facts and solving pages of problems. They wanted science education to be about gaining an understanding of scientific conceptual knowledge (Hodson, 1992) and an "understanding what the conduct of science involves, that is, taking part in the activities that contribute to the development of skills with which to obtain reliable scientific knowledge" (Justi & Gilbert, 1999). In short, more attention was focused on teaching students the nature of science. Thus, the goal of science education was to teach students to "do science" as scientists do.

In spite of small pockets of successful reforms, most introductory physics courses are still taught traditionally (using textbooks, lecture and demonstration) with the intent that students would "understand" the topics instead of just solving problems. The reform programs and the few traditional physics courses that demonstrate some improved conceptual understanding by students have a common constructivist theme: student learning is enhanced and their conceptual understanding increases when they are actively engaged in constructing their own knowledge (Halloun, 1984; Laws, 1991; Mazur, 1997; Thorton & Sokoloff, 1990, 1998; Wells, 1987; Wells, Hestenes, & Swackhamer, 1995). One thing that many of these successful programs have in common was that they attempted to help students use models (mathematical, mental, physical, etc.) to construct and reconstruct their understanding.

In summary, in order to help students truly learn physics and abandon their misunderstandings of major physics topics, the goal of physics education is changing in two ways. First, there is a push away from students solving pages of problems and toward students developing a conceptual understanding of physics topics. Second, in order to help students make that shift, educators began focusing on the nature of science because they wanted students to "do science" as a scientist does. As noted above, research indicates that although traditional instruction is not the best method to meet those goals and often does not make significant headway in changing student misconceptions about physics phenomena; it is the most common method of instruction. Furthermore, research has shown that when learning about the nature of science becomes a theme in physics courses, students show significant gains in understanding the nature of science without declines in content acquisition (Fishwild, 2005).

Thesis Statement

This dissertation details efforts to uncover and probe the relationship between changes in student conceptual understanding of electricity and magnetism topics (E&M) and their knowledge about models in science.

Purpose of the Study

The purpose of this study is to inform instruction by increasing the body of knowledge regarding the relationship between student knowledge about models in science and their conceptual understanding with regard to electricity and magnetism (E&M). The study is unique because previous studies on conceptual understanding in electricity and magnetism focused on non-traditional physics instruction and failed to examine how student views of the models in science and the learning of science are related to their improvements in conceptual understanding (Ding, Chabay, Sherwood, & Beichner, 2006; Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001). Clement and Steinberg (2002) studied student model evolution or the incremental growth of student models over time and found that such growth is important to conceptual learning. Others (Gutwill, Frederiksen, & Ranney, 1992) noted that the "flexible use of models held simultaneously was important to the development of expertise in the area of electric circuits." While previous studies have examined conceptual change with regards to E&M content during traditionally taught physics courses (Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001) and others have detailed changes in students views about models and modeling in traditional physics courses (Treagust, Chittleborough, & Mamiala, 2002), none have examined the relationship between students views of models in science and changes in conceptual understanding in a traditionally taught physics course.

Theoretical Framework

The theoretical framework for this study is cognitive constructivism. The cognitive constructivist notion that students construct knowledge for themselves is critical to understand how students learn physics. Piaget's (1952) notion that individuals do not assimilate what they are given or passively store information, but actively construct it by acting on and operating on ideas is one of the basic premises of using models to teach science and to enhance conceptual understanding. In addition, cognitive constructivists, in particular those who follow Piaget, believe that when students encounter new knowledge that conflicts with existing knowledge, the student is forced to adjust his/her frame of reference to accommodate the new information.

In physics, students enter the course with ideas or mental models of how "things work" often called pre-conceptions. However, in most cases, these pre-conceptions differ from the correct or expert view. In fact, Halloun and Hestenes (1985a) note that through cognitive research, it has been established "that the perceptions of people untutored in physics are naturally inconsistent with classical mechanics in almost every detail." One goal of physics education is to help them overcome or change these views (Clement, 1982; Dykstra, Boyle, & Monarch, 1992; Halloun & Hestenes, 1985a, 1985b; Hammer, 1996b; McCloskey, 1983; Strike & Posner, 1985). Throughout the physics course, as students encounter the correct physical concepts, they must reconstruct their pre-conceived ideas or mental models to account for the new information. This construction-reconstruction of models is what scientists do as they pursue scientific knowledge.

Hence, the use of models in pursuit of science is constructivist in nature because models, whether they are mathematical, physical, or mental, are altered as new knowledge emerges or to fit a specific situation.

In summary, how students reason or perform in a physics course may be affected by both their prior understanding or their alternative conceptions (cognitive constructivist point of view) and it may be related to whether or not they view the physics course as a place to see, examine, discuss, alter, and evaluate multiple points of view. For example, "it is routine among physicists . . . to [create models that] suppose ideal, unattainable conditions . . . [but] to non-physicists, including students, it may be difficult to understand this practice and how it should be invoked (Hammer, 1996b). This study examines how student understanding of the nature of science, in particular the use of models to learn and do science, is related to changes in their conceptual understanding of E&M topics.

Statement of the Problem

It is well documented that students in teacher-centered, traditional-lecture introductory physics classes do not demonstrate as high a level of conceptual understanding on basic concepts as instructors would hope (Hake, 1998; Halloun & Hestenes, 1985a, 1985b; Hilborn, 1997; Laws, 1991; McDermott, 1991; McDermott, 1993; McDermott & Schaffer, 1992; McDermott, Schaffer, & Somers, 1994; Schaffer & McDermott, 1992; Thacker, Kim, Trefz, & Lea, 1994; Thorton & Sokoloff, 1998; VanHeuvelen, 1991b). In particular, students show very little gains in problem-solving skills that allow them to apply physics in real-world situations and critical thinking skills that aid them in understanding the world around them (Hilborn, 1997). More importantly, students taught using the traditional learning method typically leave the course with the same misconceptions about science that they had when they entered the course (Elby, 2001;

Hake, 1998; Lising & Elby, 2005; Redish, 1994b). For example, students can solve electric current and magnetic field problems but do not grasp the connection between magnetism and electric current. It has also been shown that students can solve 1000 traditional physics problems without overcoming their conceptual difficulties in understanding the topic (Kim & Pak, 2002). In other words, students can solve the paper and pencil problems but cannot explain why or how the physics “works” and cannot apply the physics concepts to real-world situations.

In addition, Hestenes (1995) provided another perspective on the inadequacies of traditional physics instruction when he notes student poor performance on graduate oral examinations, in particular, when they are asked to apply knowledge or demonstrate their conceptual understanding of a particular topic. He states that this poor performance is an indicator that traditional instructional techniques do not adequately develop student abilities in qualitative modeling and analysis. Redish (1999) also notes that “traditional lecture-based instruction demonstrates that a reasonably good understanding of science can be taught to only a select 5% of the population” and that constructivist methods or particular attention to conceptual development show significantly better results.

More recently, studies have shown that student ability to produce, use, and understand models in the learning and doing of science is particularly weak, and that students demonstrate a “limited understanding of the nature of science and how scientists conduct their business” (Coll, France, & Taylor, 2005; Gobert, 2000; Justi & Gilbert, 1999; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001). However, there is a lack of studies that link the relationship between student-held views of models and the use of models in science with any corresponding expert understanding of E&M topics.

Research Questions

One goal of science education is for students to learn “to do” and understand science like a scientist conducts his business, not just to solve science problems at the end of the chapter (Dunbar, 2000) . With that in mind, this study documents student views on models in science and in learning science in order to gain a deeper understanding about how those views relate to the development and changes in their conceptual understanding of electricity and magnetism topics. In particular, this study will explore to what degree student understanding of the nature of models in science impacts their conceptual understanding of electricity and magnetism. The research questions that are answered in this study are:

- How does traditional physics instruction in E&M alter student views about models in science?
- To what extent does traditional physics instruction in E&M alter student conceptual understanding of E&M topics?
- What is the relationship between student understanding of models in learning and doing science and conceptual understanding of E&M?

Method of Investigation

This study reports on a semester-long study of college students enrolled in the second course of a two-semester sequence of introductory physics courses. The students had previously completed the first-semester course which covered Newtonian physics and were enrolled in the second-semester course which covered electricity, magnetism, light, sound, and thermodynamics. The students received traditional physics instruction with no additional attention to the nature of science and the use of models in doing and learning science. The students were administered the Conceptual Survey in Electricity and Magnetism (CSEM) (Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001) and Student Understanding of Models in Science (SUMS) (Treagust, Chittleborough, & Mamiala, 2002) as a pre- and post-test.

Need for the Study

Since the early 1980s, the goal of science education has become more than having students memorize a series of facts and solve a list of problems. There is a push to create critical citizens with an overall understanding of science and the nature of science so they can compete in a global economy and function in a new and different world (AAAS, 1990; Freidman, 2005; Justi & Gilbert, 1999). Justi and Gilbert (1999) also note that in order to produce critical citizens, it is important that students learn more than just scientific knowledge, they need to learn the process of science. The problem with science education, physics in particular, is that it is failing to meet this emerging need. It is estimated that 96% of students who take introductory physics courses never take another physics course. In addition, “most will say that fewer than 15% of the students ‘get it’ in the calculus-based introductory physics course. The fraction is even smaller in the algebra-based class” (Redish, 2000).

Although there are efforts to reform introductory physics instruction, these reform methods continue to impact only a small number of students at select universities (Chabay & Sherwood, 2007a; Halloun, 1984) and traditional instructional courses continue to outnumber the reform courses. As previously noted, introductory physics courses taught using the traditional lecture method (1) do not meet the needs of the students, (2) fail to develop student conceptual understanding, (3) do not remove misconceptions about physics, and (4) do not increase student understanding of the nature of science. The result is that most students who take introductory physics in college are failing to attain what many would consider to be a primary goal for such courses: a scientific understanding of phenomena that utilizes the perspective of physics.

Since one of the keys to learning science is the use of models (Chapman, 2000) and that the growth and sophistication of student models is important to developing expert knowledge (Clement & Steinberg, 2002), it is important to analyze the topics together using data from the predominant method of instruction in college physics courses today. In this study, models are internal constructs used to explain and make predictions. A more detailed definition is included in the glossary below and in Chapter 2. To date, there is a significant lack of literature that documents the relationship between student views of models in science and the development of conceptual understanding on abstract topics such as electricity and magnetism. This study will inform physics instruction by documenting specific views of the nature of science, in particular models in science, that relate to improved conceptual understanding in electricity and magnetism.

Significance of the Study

There is a plethora of studies examining conceptual development in Newtonian physics (Chi, Feltovich, & Glaser, 1981; Clement, 1982; Dykstra, Boyle, & Monarch, 1992; Gunstone, 1987; Halloun, 1984; Halloun & Hestenes, 1985a, 1985b; Hammer, 1996b; Hestenes & Wells, 1992; Hestenes, Wells, & Swackhamer, 1992; Kim & Pak, 2002; Maloney, 1984; McCloskey, Caramazza, & Green, 1980; Otero, Johnson, & Goldberg, 1999; Ploetzner & VanLehn, 1997; Thorton & Sokoloff, 1990, 1998; Trowbridge & McDermott, 1980a, 1980b; White, 1983) with an overwhelming consensus that an understanding of models in science is important to improved conceptual understanding (Hake, 1998; Hestenes, 1996; Laws, 1991; Lehrer & Schauble, 2000; Lesh & Doerr, 2003; Schober, 2006; Taylor, Barker, & Jones, 2003; Thacker, Kim, Trefz, &

Lea, 1994; Vensenka, Beach, Munoz, Judd, & Key, 2002; Wells, 1987; Wells, Hestenes, & Swackhamer, 1995). However, there is a serious lack of studies for other topics in physics such as E&M. It seems that there is a general assumption is that if it works with Newtonian concepts, it must work across the board. While that assumption may be true, it still leaves a gap in the knowledge that informs instruction on E&M.

It has been established that conceptual change is difficult to achieve (Arons, 1997; Carey, 2000; Kuhn, 1970), that students enter science courses with misconceptions (diSessa, 1993; Hammer, 1996a; Smith, J. P., diSessa, & Roschelle, 1993) and that misconceptions in Newtonian physics are especially difficult to overcome (Clement, 1982; Clement, Brown, & Zeitsman, 1989; Halloun & Hestenes, 1985a, 1985b; Hammer, 1996b). Since students do not have first-hand experience with E&M topics in the same way as they do with motion, it is hard to assume that their misconceptions are as difficult to change as they are in Newtonian physics. For example, students live with and experience motion every day and make assumptions about how it works through these everyday experiences. Research indicates that even after a course in Newtonian physics, most students possess the same misconceptions they started with (Hestenes & Wells, 1992; Hestenes, Wells, & Swackhamer, 1992). However, their experience with E&M is limited in that they do not "see" what happens the same way. Flipping a light switch and noticing the light come on does not provide the same sensory and physical experience that gravity and other Newtonian concepts might. Thus, it is reasonable to assume there is still much to learn about how students learn E&M concepts and how this experience is different from learning Newtonian physics. In addition, analyzing the E&M data through the lens of what students know and understand about models in science is unique. There have been no studies that examine the connection between student understanding about models in science and their conceptual development in E&M. This is significant because so much of the conceptual understanding in E&M requires the use of models.

Definition of Terms

Electricity & Magnetism (E&M) – topics included in a course on E&M include: DC circuits, charge, electric fields and potential, magnetic fields and forces, electrostatics, electromotive force and current, and capacitance

Expert view (consensus model) – the commonly accepted view/model of the scientific community

Misconceptions (alternative conceptions or naive conceptions) – a preconception that is contrary to the expert view or what is commonly accepted as fact

Models – constructs used to explain and make predictions about phenomena, observations, and data. The two categories of models are: mental and expressed models. A more detailed explanation can be found in Chapter 2.

Mental Models – internal representation of external reality (In this study, the term model refers to mental model unless otherwise stated.) A more detailed explanation can be found in Chapter 2.

Model Analysis – A data analysis technique that uses "qualitative research results to provide a framework for analyzing and interpreting the meaning of students' incorrect responses on a well-designed research-based multiple-choice test" (Bao & Redish, 2001)

Novice/Naïve view – the ideas or models held by individuals that differ from the expert view

Preconception – an idea or model possessed by individuals prior to instruction

Science – a system or process for acquiring knowledge

Limitations

The findings from this study are limited to conceptual development in electricity and magnetism and may not generalize to other physics topics such as optics, thermodynamics, and quantum physics. Also, since understanding of topics in electricity and magnetism requires student knowledge in energy, and Newtonian physics areas such as force and motion (Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001), this study does not attempt to determine how student performance on previous physics topics affects performance on this assessment. For example, calculating electric fields and gravitational forces require similar vector operations (Chabay & Sherwood, 2008) yet this study does not address how student ability to apply vector operations in a physics context affects their performance on E&M tasks.

In addition, the population studied was college students at one university enrolled in introductory physics (where high school physics is not a pre-requisite for admission to the university). This may prevent the findings to be generalized to include students at other universities with varying ability levels and pre-college physics background. Finally, science reform efforts at the elementary and secondary level may prove successful in deepening student knowledge of the nature of science and thus, the use of models in science and in the learning of science. As a result, upcoming students may have a more sophisticated view of the use of models and any inferences drawn from this study might not apply to the new population. Although at this time, there are no data to support or refute this assertion; further study is needed to determine if this is indeed happening.

Summary and Overview of the Study

Traditional physics instruction is the norm for most introductory physics courses across the nation. Efforts have been underway to improve student conceptual understanding of physics and to improve their views of the nature of science. Many reform programs have proven effective but are limited in implementation sites. This study will build upon the knowledge base of physics education reform by providing insight into methods to enrich traditional instruction. It will examine the correlation between student views of the nature of science (in particular, their understanding of models and the use of models in science) and changes in student conceptual understanding in electricity and magnetism. Two established assessment instruments will be used to collect the relevant data. The Conceptual Survey of Electricity and Magnetism (CSEM) will be used to determine what misconceptions students present at the beginning of instruction and which are changed at the conclusion of instruction. The second assessment instrument, Student Understanding of Models in Science (SUMS) will examine student views of models in science.

CHAPTER 2 – LITERATURE REVIEW

Introduction

The literature review for this dissertation examines how student views of models in science affects conceptual understanding of electricity and magnetism (E&M). In order to do so, the results are correlated from two established assessments (Student Understanding of Models in Science or SUMS and the Conceptual Survey of Electricity and Magnetism or CSEM) discussed in detail later in this chapter. In addition, a relatively new data-analysis technique called Model Analysis (MA) was also used. This chapter gives an overview of MA, then a review of the literature related to student learning necessary to understand the findings of the study. The review will include student misconceptions as they relate to problem solving and learning. Also, details about the assessments that were used in this study are included.

Model Analysis

Model Analysis (MA), was developed to quantitatively examine the qualitative reasoning of a group of students on a particular concept. It relies on the cognitive constructivist framework that students possess mental models of physical concepts and that students apply those models inconsistently when solving problems (Bao & Redish, 2001). MA, assumes that just as light behaves both as a particle and a wave, a student may employ more than one model to solve a problem. It is particularly appropriate for this study because the progression of, or the increase in the sophistication of, student models is important to understanding science learning. Additionally, Clement and Steinberg (2002) found that “flexible use of multiple models held simultaneously was important to” student learning about electric circuits.

MODEL ANALYSIS AND COGNITIVE LEARNING THEORY

It has been established that students may hold contradictory views or elements of a mental model in their mind without being aware of it (Redish, 1994a) and that they often employ these inconsistent models alone, or in combination, to solve problems. When students use a combination of models to solve problems, they are said to be mixing models. Researchers have found that students mix models because they tend to confuse similar elements of different models, apply portions of fragmented models or lack a set of coherent rules as to when to apply each model. (Bao, Hogg, & Zollman, 2002; Bao & Redish, 2001; Driver, 1989; Hestenes, 1987; Redish, 1994b).

As students learn, these models are adapted to incorporate new knowledge or reinforced with new experiences. Thorton and Sololoff (1998) and others (Bao, Hogg, & Zollman, 2002; Bao & Redish, 2001) found that not only do students have and use these coexisting conflicting views, but also that during the learning process they move from the incorrect view through a mixed-use state toward the correct view. Although a new data analysis tool, MA has been accepted by many in physics education research after Bao and others (Bao, Hogg, & Zollman, 2002; Bao & Redish, 2001) demonstrated its effectiveness through an examination of the results of the Force Concept Inventory and later, Newton's third law. In this study, MA is used to present a detailed description of the states of student understanding on several E&M topics.

PURPOSE OF MODEL ANALYSIS

Model Analysis is used in this study because it gives more information than just whether or not the students answered correctly or are able to apply the correct/expert model to solve physics problems. MA indicates whether the student is likely to use a particular model on other problems related to the concept. This allows researchers to build a picture of the particular contexts within which it is difficult for students to apply the correct model, and specific features or contexts that affect student learning (Bao, Hogg, & Zollman, 2002). By accepting Redish's (1994a) statement that the "goal of physics teaching is to have students build the proper mental models for doing physics" then students should be able to qualitatively reason about physical processes by organizing content into easily accessible mental models so they can think and work like a physicist. MA allows instructors to analyze the models students are using and determine the effectiveness of instruction through feedback based on the probability a student will use a particular model to solve similar problems. Instructors can then provide specific learning situations to help change student misconceptions and build upon their mental models to attain a more expert conceptual understanding of the topics.

QUANTUM THEORY AND MODEL ANALYSIS

Classical physics is characterized by the accurate measurement of position and momentum of objects. However, inherent in quantum physics is uncertainty in the relationship between position and momentum. Model Analysis applies this quantum notion to how students apply mental models to solve problems. Bao (1999) makes the analogy of a particle to the way students use models to solve problems. There is uncertainty in the way students apply the expert and naïve models just as there is uncertainty in the position and momentum of a particle. In quantum physics, information about the state of a particle is described as a wave function. In Model Analysis, models are analogous to a particle and thus can also be described by a wave function. This analogy makes sense because both a particle and model use can exhibit behavior which seems to contradict each other. A particle can behave as a particle or as a wave and students can employ the contradictory expert and naïve models to solve problems. Therefore, the mathematics that describes a particle and its behavior applies to student model use. The MA sections in Chapter 4 will explain the mathematics used in quantum physics as it applies to Model Analysis.

In quantum physics, a wave function gives a particle's amplitude and by definition, the square of the wave function gives the particles intensity (Serway, Moses, & Moyer, 2005). The key is that the intensity of a wave is equal to the probability that the particle will be at a particular position at a particular time. This connection between the wave function and probability was first proposed by Max Born in 1925 and is still the currently accepted expert view (Serway, Moses, & Moyer, 2005). Similarly, in MA the student model use is represented as a wave function and thus, the square of the wave function gives the probability that the student will use a particular model at a particular time.

At this point, it is important to emphasize the difference between statistical probability and probability (or the probability function) in the quantum world. In traditional statistics, probability represents the degree of knowledge of an actual situation. For example, there is a one in six chance of rolling a three on a six sided die. However in quantum mechanics, the probability function represents the tendency for something to occur. The quantum probability function represents a tendency for events and our knowledge or lack of knowledge of those events (Heisenberg, 1999).

Heisenberg (1999) describes a theoretical interpretation of an experiment in quantum physics as having three phases. The first is the translation of the initial experiment into a probability function. The second phase is more abstract. It is the change to the system over time and cannot be described in classical contexts. Finally, the third phase involves taking a new measurement of the system and using the probability function to calculate the result. Heisenberg (1999) gives the following example: The position of an electron is measured in phase 1 and again in phase 3. Since there is no way to observe the orbit of the electron around the nucleus, there is no way to tell where the electron was between the observations (phase 2). In classical physics, it would make sense to say the electron was on a path between the phase 1 and phase 2 positions. The idea that the electron is on a path is the idea of continuous change; the electron moves from one place to the other in a predictable, continuous way. However, in quantum physics this is not an appropriate conclusion. Quantum physics is characterized by an instantaneous and discontinuous change or the notion that the electron is "here" and then "there" and "everywhere" (Heisenberg, 1999; Polkinghorne, 2002). MA follows the same pattern. Student model use is observed during the pre-test (phase 1) and again at the post-test (phase 3). Just as in quantum physics, researchers may never know precisely what occurs during the discontinuous process in phase 2. However education researchers can look for clues to better understand how students learn in phase 2. This study takes the measurements at phase 1 and phase 3 in order to identify areas of further study. The changes or lack of changes between phase 1 and phase 3 measurements are identified and discussed.

Nature of Science

As discussed in Chapter 1, the focus of science education has shifted to include teaching students about the nature of science. One of the purposes of science education is to teach students to "do" science like a scientist. This implies that students must become proficient at the process of scientific inquiry. Models and the use of models is an essential part of the nature of science, in particular scientific inquiry (Giere, 1988; Gilbert, J. K. & Boulter, 2000); therefore, a discussion of the nature of science is included in this literature review.

Researchers (Coll, France, & Taylor, 2005; Fishwild, 2005; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Moss, Abrams, & Robb, 2001; Schwartz, R. S. & Lederman, 2002;

Smith, C. L., 2000; Smith, M. U. & Scharmann, 1999) have found a great discrepancy in how scientists and novices (including students and the general public) view the nature of science. Scientists believe that science is an ongoing process that requires repeated observations to be legitimate. They also know that it is subjective, fallible, and continuously changing. The same researchers also document novice understanding of the nature of science. They found that novices see science as entirely objective with a set of unchanging facts, laws, procedures, and rules. Novices also do not believe scientists are creative in their work (Halloun & Hestenes, 1998).

As a result, there has been a movement in science education to provide students with a more legitimate, authentic view of science. The goal is to provide a better understanding of what scientists "do," how they "do it." Essentially, the focus of science education shifts from memorizing facts to learning a process to make sense of the world (AAAS, 1990).

One such effort to improve student understanding of the nature of science is through an increased emphasis on models and the use of models in science (Franco, Barros, Colinvaux, Krapas, Queiroz, & Alves, 1999; Greca & Moreira, 2000). Gilbert (2004) and others (Coll, France, & Taylor, 2005; Ogborn & Martins, 1996) argue that because models play such an essential role in the practice of science, attention to models and modeling should take a more prominent role in order to make science education more closely resemble the pursuit of scientific discovery. Similarly, others (Dagher, 1994; Gilbert, S. W., 1991; Tomasi, 1988; Treagust, 1993) note that models are essential to research along with the production, dissemination, and acceptance, of scientific knowledge. Hodson (1992) remarks that "learning to do science" is one of the most important purposes of science education. Learning to do science requires that students learn to create, test, and communicate their own models (Greca & Moreira, 2000; Justi

& Gilbert, 2002). Fishwild (2005) found that students who received instruction specific to the nature of science and consequently less time on content showed greater understanding of the nature of science and did not score significantly lower than those who did not on the Force Concept Inventory, a test of conceptual understanding on Newtonian physics topics.

Models

A general definition of a model is a representation of something. It can be a theoretical or hypothetical description, a plan, something to be imitated or copied, or a visual replica. It can be an internal construct or an external representation. The next section describes, in detail, the different types of models used in science.

TYPES OF MODELS

The most common models used in science are mental models and expressed models. Mental models and expressed models are defined and explained below.

Mental Models

A mental model refers to the abstract representation that aids in understanding, explaining, communicating, or visualizing a process, phenomenon, property, or other occurrence. It is an individual's internal or cognitive representation of an idea, object, theory, process or phenomenon. For example, the parts of a cell compared to the parts of a city is a model used by students to understand how the parts of a cell function. It is not a scale model, a sample for examination (such as a model airplane), or a visual replica (such as an architectural model of a building.) A mental model is a cognitive construction or internal schema used to describe and explain phenomena that cannot be experienced directly (Coll, France, & Taylor, 2005; Ritchie, Tobin, & Hook, 1997; Smitt & Finegold, 1995). In addition, mental models are dynamic in that they are expected to change as students encounter new information (Vosniadou, 1994). They are not necessarily correct or complete, and are unique to each individual, since each person constructs his own. They are the "the collection of mental patterns people build to organize their experiences related to a particular topic" (Redish, 1994a). There are three types of mental models: working models, analog models, and thought experiments. The three types of mental models are described in Table 1 (Karplus, 2003) below and a discussion of each follows the table.

Table 1 – Types of Mental Models

Type of Model	Definition	Examples	Limitations	Advantages
Working Models	Simplified mental images for physical systems that are idealized and abstractions from reality	– Sphere model of the earth – Particle model for the sun and planets	Simplified or idealized representation where many complexities are ignored (such as the topography of the earth in the sphere model)	Make the unfamiliar familiar and allow for easier manipulation by separating the extraneous information in order to focus on the questions at hand
Analog Models	Relates a system to another system that is more familiar or to a system that is easier to conduct experiments on	– the propagation of waves of radio waves analogous to the waves created on the surface when a rock is dropped into a still pond – the human circulatory system analogous to the hot water system in a residence	Limitations of the analogous system can lead to erroneous conclusions	The analogous system is more familiar so it can call attention to overlooked features of the original system, suggest similar relationships in the original system, and predictions about the original system can be made from known properties of the analogous system
Thought Experiments	The mental manipulation of a model so as the consequences of its operation are deduced from the properties of the model. Often called devices of imagination or Gedanken Experiments	– Einstein's Chasing Light Beams – Schrödinger's Cat – Taxation as Theft – Survival Lottery – Trolley Problem	Often challenging to learn something new without new empirical data and should not be substituted for a real experiment whenever possible	Enable scientists to make deductions from a working model, theory, or "mystery system" that can then be compared with observations – they may be used either to illustrate the validity or non-validity of a model and often help scientists to re-conceptualize the world in a different way

WORKING MODELS

The first type of model used frequently is a working model. Working models are simplified mental images for a physical system. Working models are idealized representations therefore many of the complexities of the system are overlooked. This simplification allows for better manipulation of the model in order to isolate and draw conclusions about the characteristics studied. However, the simplification can lead to misinterpretation and erroneous conclusions. For example, the spherical model of the earth ignores the topography of the surface of the earth (Karplus, 2003) and can lead to the invalid conclusion that the surface earth is completely smooth.

ANALOG MODELS

Analog models are simply analogies used to relate an unfamiliar system to something more familiar in order to call attention to subtle features of the unfamiliar system, suggest relationships, or make predictions about the new system based on characteristics of the familiar system. Although radio waves propagate in all directions, the process can be considered analogous to the surface waves created when a rock is dropped in a still pond.

THOUGHT EXPERIMENTS (GEDANKEN EXPERIMENTS)

Another controversial yet powerful type of model employed by scientists and in modeling instruction is thought experiments or Gedanken experiments. Einstein made thought experiments famous by using them to help him develop and explain quantum theory. Essentially, a thought experiment (TE) is a mental exercise that manipulates a model according to known laws and restrictions. It is controversial because it is not based on new empirical data. Others (Velentzas, Halkia, & Skordoulis, 2005) have noted that “TEs have played an important role in the development of science because they were used by leading scientists for the formulation of innovative theories, the establishment of contradictions in already existing theories, the modification of the old theories according the new findings, or even for their replacement with a new paradigm."

Thomas Kuhn states in his work: *A Function for Thought Experiments* that "a well-conceived thought experiment can bring on a crisis or at least create an anomaly in the reigning theory and so contribute to paradigm change. Thought experiments can teach us something new about the world, even though we have no new empirical data, by helping us to re-conceptualize the world in a better way" (Kuhn, 2007). TEs employed under the correct circumstances do not need new empirical data because scientists are not trying to discover new knowledge but better understand the information at hand.

Thought experiements are also very effective at communicating complex science to non-scientists. TEs can be used both as constructive tools for clarification or innovation or as destructive tools by destroying or highlighting serious problems with a theory or model (Brown, 1991). Velentzas, Halkia, & Skordoulis (2005) note that TEs are important tools in the classroom because they focus on conceptual understanding, inquiry, communication in a scientific environment, and the role of collaboration in science. In addition, Velentzas, Halkia, & Skordoulis (2005) also note that early research shows the "narrative techniques used in popular science books to present TEs proved to be very attractive to students." TEs are also used by researchers to provoke subjects to think about ethical issues such as the Trolley Problem (a trolley with five people going down a track out of control and the subject can flip a switch to save the lives of the five people on the trolley but it will kill one person on the other track) or the Survival Lottery (since organ donation can save more lives than the one it kills, individuals are asked to give their life to save many by donating their organs.) Anarchists even use TEs to promote taxation as theft (the assumption that the government is violating personal property rights by collecting taxes.)

Expressed Models

Mental models can be represented externally for others to examine. When mental models are represented externally, they are called *expressed* models (Coll, France, & Taylor, 2005). The most common expressed models are mathematical, physical and computer models. Once the model is built, scientists examine its inadequacies in order to gain new understandings and develop even more robust models (Karplus, 2003) so the process may repeat and more informative or appropriate models may be constructed in order to deepen the understanding about a phenomenon. As the community of scientists refine and test expressed models, one or more models will gain acceptance and will come to be known as the *expert* or *consensus* model (Coll, France, & Taylor, 2005). Table 2 contains a description of the expressed scientific models (Chabay & Sherwood, 2007a, 2007b; Karplus, 2003). A discussion of each follows the table.

Table 2 – Expressed Scientific Models

Type of Model	Definition	Examples	Limitations	Advantages
Physical Models	A representation using objects	– scale model such as an architectural model – mold such as one used to make dentures	All functions and conditions are not represented in the model and expensive/difficult to build/manipulate	Allows researchers to monitor and measure the effects of manipulation in a contained environment
Mathematical Models	A mathematical way of describing a relationship or the behavior of a system	– Ohm's Law $I = \frac{V}{R}$ – Population Growth Curves	Not an exact reproduction or representation of what is actually occurring – accuracy depends on the amount of a priori information available, and the reliability of the measured quantities	Usually easy to apply and allows for examination of the effects of changes on one or more variables
Computer Models	An algorithm that predicts the results of a process or simulates how a given set of conditions will change over time or under certain constraints	– weather models such as hurricane tracking models – numerical calculations based on the Momentum Principle to watch the dynamic evolution of the behavior of a system	Created from data or based on working models, thought experiments or mathematical models – it is only as accurate as the data or models from which it was created	Makes it possible to analyze complex systems which otherwise would require very sophisticated mathematics or which could not be analyzed at all without a computer

PHYSICAL MODELS

Physical models play an important role in the pursuit of scientific understanding. Scientists build physical models in order to monitor and measure the effects of their manipulation in a controlled environment. For example, civil engineers and architects build models of buildings and cities only to use them in a simulation to determine how they will withstand the forces of an earthquake. Coastal engineers use physical models to determine how the rate of coastal erosion is affected by mitigation efforts.

MATHEMATICAL MODELS

Mathematical models are important in drawing conclusions, describing behavior, and analyzing relationships. They can be as simple as the linear relationship of Newton's second law of motion ($F = ma$) or as complex as the differential equations used to model the motion of particles. Experimental mathematical models are heavily dependent on *a priori* information but allow for easy manipulation of one or more variable. Mathematical models are commonplace in all aspects of physics courses, including electricity and magnetism, as seen by the vast array of formulas. In fact, just about all physics theories or laws are expressed as mathematical models.

COMPUTER MODELS

Finally, computer models are used as a critical means for testing complex problems that may not normally be calculated by hand. They are usually based on mathematical models or on a combination of numerous mathematical models. Population curves, the complex models used to predict the weather and the path of hurricanes, and physics principles applied to engineering problems, are a few examples. The great advantage to computer models is the speed at which simulations may be run and variables may be changed. Chabay and Sherwood (2007b) note in their modeling instruction textbook covering electric and magnetic interactions that "real time 3D animations are generated as a side effect of student computations, and these animations provide powerfully motivating and instructive visualization of fields and motions." The danger of computer models is best expressed by Pierre Gallois (2007) when he wrote: "If you put tomfoolery into a computer, nothing comes out of it but tomfoolery. But this tomfoolery, having passed through a very expensive machine, is somehow ennobled and no-one dares criticize it." There is some recent research on using computer simulations in physics courses (Chabay & Sherwood, 2008; Chonacky & Winch, 2008; Cook, 2008; Rebbi, 2008); however, computer modeling is not used in courses described in this study.

Use of Models in Science

Researchers (Coll, France, & Taylor, 2005; Penner, Giles, Lehrer, & Schauble, 1997) note that the work of professional scientists is dominated by the building, and testing of models.

In addition, these researchers propose that understanding the role of models "is the link between the two worlds" of science and science education. For example, as scientists build a scientific theory, they combine the various types of models above to create a working or analog model. Then, they often conduct thought experiments in an attempt to verify or "poke holes" in the model. As they become more confident in their theory, mathematical and/or physical models are developed. In complex situations, computer models may be developed as well. It is important to note that all "physical theories have limitations imposed by the inadequacies of the models and the conditions of the thought experiments" (Karplus, 2003). Often, the term theory and model are used interchangeably. Manfred Eigan (2000) sums up the difference between the two: "A theory has only the alternative of being right or wrong. A model has a third possibility; it may be right, but irrelevant." In reality, theories are built on models (working models, analog models, mathematical models, and computer models are the components of a theory) but more complex models may be built on existing theories and the process continues. The diagram below illustrates the building of a simple theory. See Figure 1.

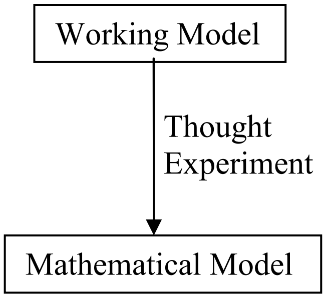

Figure 1 – Building a Simple Theory
(Karplus, 2003)

Coll, France and Taylor (2005) note that "in order to successfully develop a conceptual understanding in science, learners need to be able to reflect on and discuss their understanding of scientific concepts" and the models they are learning. Students who are able to construct their own models and then critique them show the greatest gains in conceptual understanding (Hestenes, 1987; Wells, 1987; Wells, Hestenes, & Swackhamer, 1995) as opposed to students who do not have a grasp of the nature of science often believe that models are facts and are unable to critique and revise their models (Fishwild, 2005; Halloun & Hestenes, 1998).

Misconceptions

As detailed in chapter 1, students enter physics courses with a host of difficult to change, preconceptions about how the world works. When they are inconsistent with the expert or accepted view, they are referred to as misconceptions. These conceptions are mental models the student has constructed to explain how the world works. Student mental models are often incomplete, inconsistent, and contradictory. They have also been shown to be very difficult to alter. In addition, student-constructed rules and procedures for applying them may not provide a correct or coherent framework for when and how they are to be used. (Chi, 2005; Driver, 1989; Hestenes, 1987; Redish, 1994a; VanHeuvelen, 1991a; Wittmann, Steinberg, & Redish, 2002).

In order to be successful, students need to be able to distinguish between sometimes contradictory models (Wittmann, Steinberg, & Redish, 2002) and put the "pieces" of knowledge they hold into a coherent knowledge structure (Scherr, 2007) that enables them to solve complex and/or qualitative problems. Clement, Brown and Zeitsman (1989) point out that "not all preconceptions are misconceptions" and that students learn best when instructors provide the opportunities and experiences students need to build on those preconceptions that are consistent with consensus views.

There are several alternative views of misconceptions. diSessa (1993) considers the fragmented notion of misconceptions and believed that misconceptions are "a set of loosely connected ideas" called p-prims and students combine these p-prims when attempting to solve problems. Conversely, others (Clement, Brown, & Zeitsman, 1989) see misconceptions as alternative explanations students develop based on their experiences and they can be built upon or changed. In both cases, experts agree that student knowledge may or may not be correct. Chi (2005) holds that the views of misconceptions described by diSessa (1993) and Clement, Brown, and Zeitsman (1989) are not mutually exclusive. Scherr (2007) confirmed Chi's findings with her work in special relativity. She noted that students hold misconceptions and in addition, employ what she called "pieces models" to solve problems. She called it "pieces models" because she found that student knowledge is incomplete and they apply a combination of their coherent naïve theories and pieces of knowledge when solving problems.

It is also important to note that students solve problems differently from experts. In addition, researchers (Grosslight, Unger, & Jay, 1991; Treagust, Chittleborough, & Mamiala, 2002) have established that students have different views about the nature and purpose of models. As students solve problems, conflict arises when the information they have is inconsistent with their mental models. This study examines the proposal that how they view the nature of models, the model's correctness, and their view of the ability to change or adapt the model affects their ability to change those mental models to solve the problems. Since this study examines how those different methods and views affect their ability to apply their mental models when solving E&M problems, a discussion of expert and novice problem solving and student views about the use of models follows. In this study, the researcher takes the position that students have both fragmented and coherent mental models, that they apply them in various combinations to help them solve problems, and that they do not consistently apply their mental models when solving problems that for experts appear similar. Model Analysis (MA) is used to determine what models the students use, and the contexts that affect their ability to consistently apply the correct model to solve physics problems.

EXPERT vs. NOVICE

Researchers have found that the two major differences between experts and novices in physics problem-solving are their knowledge organization and problem-solving approach. Experts organize their knowledge around basic physical principles and can see relationships, similarities, and differences among the distinct pieces of information (VanHeuvelen, 1991a). Novices on the other hand, possess a poorly organized set of facts and formulas with few connections and a lack of understanding to see relationships. (VanHeuvelen, 1991a). This isolation of knowledge may prove effective in solving problems that deal with a single concept but is detrimental when students are required to make connections to solve more complex problems or to link their “qualitative understanding to qualitative problem solving” (Sabella & Redish, 2007).

“Experts often apply qualitative representations such as pictures, graphs and diagrams to help themselves understand problems before they use equations to solve them quantitatively. In contrast, novices use formula-centered methods to solve problems. Studies in physics education have found that student problem-solving achievement improves when greater emphasis is placed on qualitative representations of physical processes” (Heller, Keith, & Anderson, 1992; Hestenes, 1987; Hestenes & Wells, 1992; Reif & Heller, 1982; VanHeuvelen, 1991a, 1991b; VanHeuvelen & Zou, 2001)

“Students attempt to solve problems by matching quantities listed in the problem statement to special equations that have been used to solve similar problems. Students move between words and equations, which are very abstract representations of the world, with no attempt to connect either representation to more qualitative representations that improve understanding and intuition" (VanHeuvelen & Zou, 2001). VanHeuvelen and Zou (2001) also note classroom strategies are very important because as novice students acquire a more sophisticated understanding and skill at qualitative reasoning, the qualitative representations take hold as robust mental models. In addition to the less sophisticated problem-solving techniques and lack of a framework to organize knowledge, experts have a more sophisticated view of models and the use of models in science.

Implications for Instruction

Redish (1994a) notes that it is very difficult to change student established mental models and others (Grosslight, Unger, & Jay, 1991; Ingham & Gilbert, 1991; Treagust, Chittleborough, & Mamiala, 2002) have found that often students do not see models in science as things that can or should change and furthermore, they do not understand that models can be used to test or develop new scientific theories. Hammer (2000) notes that it is important to focus on the productive aspects of student knowledge and that there are "two distinct needs for the development of scientific understanding (1) the formation of intellectual resources and (2) the (re) organization and application of these resources to align with scientific knowledge and practices." In response, one question this study attempts to answer is whether or not student views of the use of models in science affects their ability to (re) organize their mental models as they learn.

Elby (1999) found that students perceive "trying to understand physics well" and "trying to do well in the course" as two distinctly different enterprises. VanHeuvelen (1991b) summarizes some key points to a successful introductory physics course. He notes, based on numerous studies that to improve student learning, college courses should not assume student knowledge, background, or experiences. Students should be allowed to "confront the misconceptions that they bring to class while at the same time helping them formulate a qualitative understanding of currently accepted physics concepts" or expert views. He also notes that students need to be active participants as they construct their knowledge into a coherent global framework based around broad physical principals. In addition, they should be given experiences that help them learn the problem-solving techniques that expert physicists use to solve complex problems. This study contributes to the body of knowledge on improving physics instruction because it sheds light on the relationship between student views of models and improvements in student achievement.

Student Understanding of Models in Science (SUMS) Assessment

SUMS is a 27-item Likert scale assessment designed to measure student understanding of scientific models. Specifically, it examines student understanding of what models are and how and why they are used in science (Treagust, Chittleborough, & Mamiala, 2002). It is documented that student-views about models are naïve in that models are exact copies to explain not abstract representations that are used to develop or test scientific theories (Grosslight, Unger, & Jay, 1991; Ingham & Gilbert, 1991; Treagust, Chittleborough, & Mamiala, 2002) and that student knowledge of the nature of science (of which the use of models is a part) affects their ability to learn science (Songer & Linn, 1991). Although traditional instruction requires students to use some form of models, it does not make reference to the nature of models and how scientists conduct their business. The use of models is one way experts organize and apply their knowledge and novices do not. This study documents how student views about models change during a semester of physics instruction in E&M and how that change affects their conceptual development on the abstract topics in E&M.

THEMES EXAMINED BY SUMS

Previous research (Treagust, Chittleborough, & Mamiala, 2002) identified the five themes present in the SUMS assessment all of which examine the naïve student beliefs about models. The five themes or scales are indicated below in Table 3.

Table 3 – Themes Examined by SUMS

Theme	Description
Scientific models as multiple representations (MR)	Indicates whether or not students understand that a model has many representations and that each representation has a unique perspective
Models as exact replicas (ER)	Indicates to what extent students view models as exact copies or abstract representations
Models as explanatory tools (ET)	Indicates to what extent students view models as visual or mental tools to make the abstract more concrete or the unfamiliar familiar
How scientific models are used (USM)	Indicates whether or not students view models as tools when developing or testing scientific ideas
The changing nature of scientific models (CNM)	Indicates student understanding of the changing nature of models and the conditions under which they may or may not change

(Treagust, Chittleborough, & Mamiala, 2002)

STATISTICAL ANALYSIS OF SUMS AS AN ASSESSMENT INSTRUMENT

The developers of the SUMS assessment instrument determined that the test was both valid and reliable. An instrument is said to be valid if it measures what it says it measures and not some other topic. In this case, the SUMS instrument was found to be valid; it measures student understanding of the use of models in science. An instrument is said to be reliable if the results are consistent over numerous administrations of the test. The developers of the SUMS assessment determined that the instrument was reliable after numerous administrations (Treagust, Chittleborough, & Mamiala, 2002). A more detailed discussion of SUMS is presented in Chapter 3.

Conceptual Survey of Electricity and Magnetism (CSEM) Assessment

The CSEM is a 32-question multiple-choice test that was intended to be used for both pre- and post- instruction assessment. It is primarily a qualitative assessment of student knowledge and is designed to provide an overview of student understanding across a broad range of E&M topics (Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001). While the research on student misconceptions and pre-instructional ideas in E&M is less documented than in other areas such as Newtonian physics, the test developers were attentive to choose distractors that are indicative of current knowledge of student alternative conceptions. As a result, questions from the CSEM are candidates for MA since MA requires that alternative conceptions be mapped to multiple choice questions for analysis. Another well respected evaluation instrument for electricity and magnetism topics was developed prior to CSEM. The Brief Electricity and Magnetism Assessment (BEMA) is a 30-question multiple choice test and is also designed as a broad assessment of student learning but it is not appropriate for this study because it does not probe any particular concept in detail (Ding, Chabay, Sherwood, & Beichner, 2006).

TOPICS EXAMINED BY CSEM

The CSEM surveys student conceptual understanding in eleven important areas identified by previous research (Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001). Table 4 (below) lists the topics covered by CSEM.

Table 4 – Topics Examined by CSEM

	Conceptual Topic
Topic 1	Charge Distribution on Conductors/Insulators
Topic 2	Coulomb's Force Law
Topic 3	Electric Force and Field Superposition
Topic 4	Force Caused by an Electric Field
Topic 5	Work, Electric Potential, Field & Force
Topic 6	Induced Charge and Electric Field
Topic 7	Magnetic Force
Topic 8	Magnetic Field Caused by a Current
Topic 9	Magnetic Field Superposition
Topic 10	Faraday's Law
Topic 11	Newton's Third Law

(Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001)

STATISTICAL ANALYSIS OF CSEM

The developers of the CSEM assessment instrument determined that the test was both valid and reliable. It measures student conceptual understanding of electricity and magnetism topics (valid) and student performance on the assessment is consistent over numerous administrations of the test (reliable). They indicate that in most cases, student responses on the pre-test are usually relatively close to random guessing but post-test data yielded more consistent information. The post-test data was analyzed for validity, reliability, and discrimination. The difficulty level for all items was determined to be acceptable because it ranged between 0.10 and 0.80 (0.50 is considered ideal). In previous administrations, the discrimination of the assessment ranged between –1.0 and +1.0. (Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001). A detailed discussion of the validity and reliability of the CSEM is presented in Chapter 3.

Electricity & Magnetism Research

Studies of student difficulties in E&M have been mostly confined to DC circuits (Cohen, Eylon, & Ganeil, 1983; McDermott, Schaffer, & Somers, 1994; Peters, 1984; Schaffer & McDermott, 1992; Shipstone, 1988), how batteries discharge (Saslow, 2008) and the electric field (Rainson, Transtromer, & Viennot, 1994; Tornkvist, Pettersson, & Transtromer, 1993;

Viennot & Rainson, 1992) with little attention to other aspects of E&M (Bagno & Eylon, 1997; Bagno, Eylon, & Ganiel, 2000; Galili, 1995; Planinic, 2006). For example, it is well known that students believe that current is used up by the bulbs in a DC circuit, the battery is a constant current source, and the order and placement of the bulbs or other elements in a circuit affect the brightness of the bulbs (McDermott, 1993; McDermott & Schaffer, 1992). In addition, McDermott (1993) found that students, even after instruction, lack a sufficient model for a simple circuit. Cohen, Eylon and Ganiel (1983) determined that student models of simple circuits are not sufficient with regards to resistance and potential difference as the cause of current flow. This study will further the knowledge of student learning, misconceptions, and pre-instructional conceptions in E&M.

E&M MISCONCEPTIONS FOR THE TOPICS EXAMINED ON THE CSEM

The overriding issues that affect student understanding of E&M topics considered in this study are detailed below. Knowledge of these common misconceptions, allowed the researcher to determine which possible distractors were indicative of applying a misconception (naïve model) and which were the result of using generally incorrect or unrelated models to solve the problems.

Researchers (Allbaugh, 2004; Arons, 1997; Aubrecht & Raduta, 2004; Bagno & Eylon, 1997; Bagno, Eylon, & Ganiel, 2000; Guth, 1995; Rainson, Transtromer, & Viennot, 1994; Tornkvist, Pettersson, & Transtromer, 1993; Viennot & Rainson, 1992) have found that students have both conceptual and mathematical issues that hinder understanding of E&M topics. The conceptual difficulties are discussed first followed by the mathematical issues.

Conceptually, students show difficulty understanding the interactions of magnetic fields and electric charges. They see magnetic poles as “charged” and calculate magnetic fields whether or not the charge is moving (Maloney, 1985). In general, students confuse the properties, rules, laws and formulas of magnetic and electric fields and often use them interchangeably. As a result, students confuse the right hand rule (magnetic field and Lorentz Force Law) and the left hand rule (magnetic field and the force exerted on an electron.) Arons, (1997) proposes that textbooks compound this problem because the problems included for students to solve usually have charged particles with an initial direction that is perpendicular to the direction of the magnetic field. Thus, they believe the two are always perpendicular and that a particle's path in a magnetic field is circular.

Bagno and others (Bagno & Eylon, 1997; Bagno, Eylon, & Ganiel, 2000) determined that less than 5% students surveyed could verbalize that a changing electric field produces a magnetic field. She and others (Arons, 1997; Raduta, 2001) found that students do not understand potential difference and as a result, cannot determine if the statement "at the point where the electric field is zero, the electric potential is also zero" is true or false. In addition, Adrian and Fuller (1997) determined that students had a great deal of difficulty verbalizing the difference between force, field, force field, potential and potential difference and there was overall confusion about the cause and effects of the concepts. They also found that after instruction, students present an even more robust misconception: a potential difference is a source for electric fields with or without current.

Another major conceptual difficulty is that students fail to understand field lines. They believe that if a charge is not on a field line, it feels no force (Arons, 1997; Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001). This is related to the conceptual problems associated with Newton's Third Law. Students have difficulty understanding force at a distance. They believe that Newton's Third Law only applies to contact forces and thus does not apply to E&M since the charges are not in contact with each other. Similarly, students need to see motion to accept the existence of a field and believe motion implies force. If there is no motion there is no force and vice versa (Allbaugh, 2004; Arons, 1997; Eylon & Ganiel, 1990; Maloney, 1985; Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001; Raduta, 2001). Researchers (Aubrecht & Raduta, 2004; Raduta, 2001; Rainson, Transtromer, & Viennot, 1994) call this "field if mobility" or "cause if motion" and tie this misconception to the mathematical issue related to interpreting formulas as discussed below. Moreover, students think field lines are 2-dimensional, finite, and are paths of a charge's motion; and that field lines can begin and end anywhere but "go" from positive to negative or left to right (Rainson, Transtromer, & Viennot, 1994). Also, Allbaugh (2004) documented that student believe that the "motion of an object will slow, even stop, if the force on it decreased based upon its distance."

Finally, students have conceptual difficulties explaining what a field is. Researchers (Adrian & Fuller, 1997) have found that even after instruction, students still describe an electric field as an area, a group of charges or cloud of charges whose job it is to impart force.

Mathematically, students struggle with vectors. Not only do they often confuse force vectors and velocity vectors, they do not distinguish between scalar and vector quantities (Aubrecht & Raduta, 2004). It has been proposed, (Raduta, 2001) that another reason students believe the velocity and magnetic field are always perpendicular to each other in the Lorentz force law is that students do not understand vector products. Additionally, they "interpret formulas as if the quantities mentioned to the right of the equal sign were the cause of those mentioned to the left" (Rainson, Transtromer, & Viennot, 1994). One specific example of this mathematical issue contributing to a conceptual understanding problem is the misconception "cause if motion" noted above. Students also exhibit a very basic mathematical misconception; they assume that negative means "no". In this case, negative means "no" charge (Raduta, 2001). Although the questions on the CSEM are all conceptual and do not require the use of any formulas, some of the mathematical difficulties students exhibit may add to the confusion in the minds of the students and contribute to the use of the naïve model instead of the expert model.

NAÏVE MODELS IDENTIFIED BY CSEM TOPIC

The topics listed below were chosen for further examination in this study because the multiple choice options for each question match the common misconceptions that students possess. The naïve models most likely used by students are listed for each question. Topics 1, 6, 7 and 10 were not examined because the common misconceptions did not readily map to the multiple choice options on the CSEM assessment.

Topic 2 – *Coulomb's Law* (Questions 3, 4 and 5)

Question 3 – Students believe that the larger the magnitude of charge, the larger force it exerts.

Question 4 – Same as Question 3 above.

Question 5 – Students confuse magnitude of charge and distance of separation.

Topic 3 – *Electric Force and Field Superposition* (Questions 6, 8, and 9)

Viennot and Rainson (1992) and Arons (1997) determined that students have great difficulty with the concept of superposition and in particular its application to electric fields. In addition, Arons (1997) notes that textbooks do a particularly poor job in addressing the concept of superposition. He found that students do not realize that the superposition principle only applies to the final arranged state and that the insertion of additional charged particles will lead to the rearrangement of charge distribution. Adrian and Fuller (1997) determined that one reason students have problems with the concept of superposition is that they have a poor understanding of the concept of electric field. They do not understand that electric charges create electric fields and thus they cannot visualize the fields produced. Their study determined that students "drew vectors pointing in the wrong direction, equipotentials rather than field lines or field vectors, or a sketched a cloud of charges near the charged objects" (Adrian & Fuller, 1997).

Question 6 – Students have difficulty with vector addition and believe that negative means "no" charge.

Question 8 – Students believe that an inserted charge does not affect the field and students believe that the larger object (in this case larger magnitude of charge), the larger force it exerts.

Question 9 – Same as Question 8 above.

Topic 4 – *Force Caused By an Electric Field* (Questions 10, 11, 12, 15, 19, and 20)

Question 10 – Students assume that if a particle is moving at a constant velocity then there is a constant force acting on the particle. In addition, they believe if there is motion, there must be a force causing the motion and vice versa.

Question 11 – Students confuse the properties of magnetic and electric fields and they believe that motion implies force as stated in Question 10.

Question 12 – Students believe that if there is motion then there must be a force causing the motion as stated in Question 10.

Question 15 – Students believe that the electric field is always perpendicular to motion and that the charge "feels" no force because it is not on a field line.

Question 19 – Same as Question 12.

Question 20 – Students believe that the larger the object (in this case, the larger the magnitude of charge), the larger the force it exerts and motion implies force as stated in Question 10 above.

Topic 5 – *Work, Electric Potential, Field & Force* (Questions 11, 16, 17, 18, 19, and 20)

See above for details on questions 11, 19 and 20.

Question 16 – Students assume that the electric field "goes" from left to right.

Question 17 – Students believe that the larger distances between equipotential lines, the stronger the field. This is analogous to larger the size of an object or magnitude of charge, the larger the force it exerts as stated in Question 10.

Question 18 – Students confuse equipotential lines and field lines.

Topics 8 – *Magnetic Field Caused by a Current* (Questions 23, 24, 26, and 28) and Topic 9 – *Magnetic Field Superposition* (Questions 23 and 28)

Question 23 – Students confuse the properties of electric and magnetic fields.

Question 24 – Students believe that the larger the current (in the wire), the larger the force it exerts (on the other wire.) This is analogous to the larger the size of an object or magnitude of charge, the larger the force associated with it as stated in Question 10.

Question 26 – Same as Question 23 above.

Question 28 – Same as Question 23 above.

Topic 11 – *Newton's Third Law of Motion* (Questions 4, 5, 7, and 24)

Question 4 – See description of Question 4 under Topic 2.

Question 5 – See description of Question 5 under Topic 2.

Question 7 – Students believe that the larger the magnitude of charge, the larger the force it exerts.

Question 24 – See description of Question 24 under Topics 8 and 9.

CHAPTER 3 - METHODS

Introduction

The purpose of this study was to examine the relationship between student views of models in science and the quality of student conceptual understanding of electricity and magnetism (E&M).

Sample

This was a quasi-experimental study because students were not randomly assigned to groups. A convenience group of general physics classes at one university was selected. Two different levels of physics classes were examined. One group (n = 44) consists of students enrolled in the algebra-based course and a second group consists of the students in the calculus-based course (n = 62).

Population

One population of students participated in this study: introductory physics students in the second of a two-semester physics sequence. The students were required to complete the first course, covering Newtonian topics prior to enrolling in the second course which covers light, sound, thermodynamics, electricity and magnetism. The course was taught using traditional, lecture and demonstration.

When a study contains students enrolled in both algebra-based and calculus-based courses, researchers often divide the population into the two subgroups for the purpose of discussing the results and drawing conclusions (Laws, 1991; Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001; Redish, 2000). In general, students in the calculus-based course are pursuing degrees in sciences or engineering while those in the algebra-based course are pursuing degrees in non-technical fields and areas outside of the sciences. Therefore, the calculus-based students usually have more experience in science and mathematical courses and a higher level of interest in science. Additionally, Halloun and Hestenes (1985b) showed that mathematical knowledge and experience affect performance on conceptual understanding of physics assessments. This was further confirmed by Dixon and Moore (1996) when they verified that there is a relationship between more developed intuitive understanding of physics topics and the type of formal, mathematical strategies used to analyze physics topics. Therefore, when appropriate, the results from this study will be presented using the two sub-groups: algebra-based (AB) and calculus-based (CB).

Sampling Method

The population for this study was a convenience sample of students from one university. A convenience sample is a sample that is chosen based on logistical issues. In this study, the participants were accessible to the researcher. The students were selected to participate based on their enrollment in the traditional physics courses that cover electricity and magnetism topics.

Selection Criteria

Since this study examines conceptual development of electricity and magnetism topics, students enrolled in the physics courses covering those topics were chosen. Participation was optional. Students were not compensated for their participation but were informed that their cooperation would inform physics instruction in the future. Approximately 85% of the students who were enrolled in the courses at the end of the semester participated in the study. They were encouraged to give their best effort by the researcher, the chair of the physics department, and the course instructors. Since performance on the assessments did not count toward the students' final grade in the course, overall effort and scores may not be as high as it would have been had the test scores affected students' final grades.

Instrumentation

Two previously developed and proven instruments were used in this study: Conceptual Survey of Electricity and Magnetism (CSEM) and Students' Understanding of Models in Science (SUMS).

CONCEPTUAL SURVEY OF ELECTRICITY AND MAGNETISM

The 32-item multiple choice Conceptual Survey of Electricity and Magnetism (CSEM) was used to measure conceptual understanding on a variety of electricity and magnetism topics. It is a broad survey instrument that has been given to over 5000 introductory physics students. "Typical pre-test results are that students in calculus-based courses get 31% of the questions correct and students in the algebra-based courses average 25% correct. Post-test correct results only rise to 47% and 44% respectively" (Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001). The CSEM uses technical language and physics situations and as such, demands that successful students demonstrate specific physics knowledge. Creators of the CSEM have documented the difficulty level of the questions on the assessment to be between 0.10 and 0.80 (Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001) which is in the acceptable range with only seven items having a difficulty level greater than 0.60. Difficulty level is the percentage of students who got the item correct. Ideally, items on assessments such as the CSEM which are designed to compare student performance should have a difficulty level of 0.50. This indicates that 50% of the students answered the item correctly and 50% answered incorrectly.

Test items with acceptable discrimination indicate that students who scored well on the assessment answered that particular question correct more often than those who scored poorly. Discrimination is calculated by dividing the difference of the number of students in the low performing group (lowest 1/3 of the test takers) who get the item correct from the number of students in the high performing group (highest 1/3 of the test takers) who get the item correct by the number in one group. A moderately discriminating item is one whose score is between 100% correct and the score that would be attained by guessing. Since the CSEM has five possible answers for each question, there is a 20% chance of guessing correctly. Therefore, the ideal discrimination for each item is 0.60. The CSEM items have discrimination scores between 0.10 and 0.55. Test creators attribute the lower than expected discrimination scores to the variety in the difficulty scores. They do note that all but four of the items had values greater than the generally acceptable lower limit of 0.20 or the chance of guessing correctly (Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001).

STUDENTS' UNDERSTANDING OF SCIENTIFIC MODELS

The Students' Understanding of Scientific Models (SUMS) is a 27-item Likert scale assessment that is based on Grosslight's (1991) work on models in science education. A Likert scale is used when measuring respondents' feelings, attitudes, or beliefs. Respondents indicate how closely their opinions match that in the statement by choosing from the following list: strongly agree, agree, neutral, disagree and strongly disagree. Developed by Treagust (2002), SUMS measures students' views of models in science. Based on their responses to the items on the SUMS assessment, student thinking about models can be classified into five themes. They are: models as multiple representations (MR), models as exact replicas (ER), models as explanatory tools (ET), use of scientific models (USM), and the changing nature of scientific models (CNM).

"The reliability score [for the SUMS assessment] ranged from 0.71 to 0.84 indicating that the instrument has high internal consistency for each [theme]" (Treagust, Chittleborough, & Mamiala, 2002). A test is considered reliable if it measures what it says it measures. A reliability score of 0.70 is considered acceptable. It is also important to determine that student responses are related and consistent. Treagust (2002), indicates that “a bi-variate correlation of the five [themes] shows that student responses to each are related and consistent” (Treagust, Chittleborough, & Mamiala, 2002).

Procedures for Conduction of the Study

The researcher administered the Likert-scale SUMS instrument and the multiple choice CSEM instrument to all subjects. Those enrolled in the algebra-based physics course completed the surveys during their laboratory course. The pre-test was given on the first meeting of the semester and the post-test was administered on the last meting of the semester. The calculus-based physics students completed the pre-test during either the first or second meeting of the semester and the post-test in the second-to-last meeting of the semester.

Data Analysis and Procedure

Traditional descriptive statistics such as mean and standard deviation were calculated for both SUMS and CSEM. Reliability statistics (discrimination and difficulty levels) for each item on the CSEM post-test were calculated. CSEM pre- and post-test results were compared to determine if the post-test scores show a significant difference at the $\alpha = 0.05$ level.

Descriptive statistics such as mean and standard deviation for the individual SUMS items were calculated. In addition, similar descriptive statistics were calculated for the five themes identified. A bi-variate correlation of the five scales was conducted to determine the extent to which student responses are related and consistent. Pre- and post-test data for each of the five themes was compared to determine if there is a significant difference in scores from the pre- and post-test at the $\alpha = 0.05$ level.

Post-test data for the SUMS themes and post-test data from the CSEM was examined to determine the correlation between the individual themes identified in SUMS and conceptual understanding indicated by CSEM.

Finally, Model Analysis (MA) (described in detail in Chapters 2 and 4) was used to further examine specific changes in conceptual understanding on E&M topics. Specifically, MA was used to find incremental growth and sophistication of student models and to determine where students use multiple models to solve E&M problems.

Research Issues

A general discussion of the reliability and validity of both SUMS and the CSEM can be found in Chapter 2. A test is considered reliable if the results are consistent over numerous administrations of the assessment. A test is considered valid if it measures what it says it measures, not some other concept. Both tests were determined to be reliable and valid.

RELIABILITY AND VALIDITY

Student Understanding of Models in Science

The developers of the SUMS instrument found the instrument has a high internal consistency for each of the five themes as indicated by reliability ratings between 0.71 and 0.84. In addition, the assessment is considered valid because students' responses to each scale are related and consistent as indicated by a high level of correlation discovered through a bi-varaiate correlation of the five themes (Treagust, Chittleborough, & Mamiala, 2002).

Conceptual Survey of Electricity & Magnetism

The CSEM was deemed reliable through the use of the Kuder Richardson-20 formula. The reliability index for the CSEM was found to be around 0.75 for each administration of the test. Values between 0.7 and 0.8 are considered appropriate for well-made cognitive tests (Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001).

The validity of the test was determined by college physics professors who, based on their experience, determined that the test items did assess student conceptual understanding of E&M topics. In addition, they determined that all items were reasonable and appropriate for college-level physics students (Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001).

Research Questions

The following three questions were addressed in this study:

- How does traditional physics instruction in E&M alter students' views about models in science?
- To what extent does traditional physics instruction in E&M alter students' conceptual understanding of E&M topics?
- What is the relationship between students' understanding of models in learning and doing science and conceptual understanding of E&M?

RESEARCH HYPOTHESES

In order to answer the research questions above, six research hypotheses are addressed in this study. A brief summary of the research detailed in Chapter 2 is included behind each hypothesis in order to clarify the reason the research hypothesis is stated as it is and to show how this study expands on the current research on the topic.

Hypothesis 1: *Student understanding of models in science would not increase after a traditionally taught physics course covering electricity and magnetism topics*. (Research Question 1)

Previous research detailed in Chapter 2 indicates that without instruction in the nature of science, students show no improvement in understanding the nature of science. This study expands on previous research because it focuses on one aspect of the nature of science (models) and examines how a course in E&M which is heavily dependent on models affects student understanding of models in science.

Hypothesis 2: *After traditional instruction, students enrolled in the calculus-based course will show a more sophisticated understanding of models in science (measured by SUMS) than those enrolled in the algebra-based course*. (Research Question 1)

Previous research detailed in Chapter 2 indicates that students enrolled in calculus-based courses perform better that those enrolled in algebra-based courses on conceptual tests of physics understanding. In addition, they are science majors and have more experience and interest in science. This study expands on previous research by examining the difference between science majors (calculus-based) and non-science majors (algebra-based) students' understanding of models in science.

Hypothesis 3: *Students' conceptual understanding of E&M topics would improve after a traditionally taught physics course covering electricity and magnetism*. (Research Question 2)

Previous research detailed in Chapter 2 indicates that students do show improvement in conceptual understanding as measured by physics multiple choice tests of conceptual understanding after instruction. This study expands on previous research by examining individual E&M topics in detail, as opposed to overall performance.

Hypothesis 4: *After traditional instruction, students enrolled in the calculus-based course will have a greater conceptual understanding of E&M topics (measured by CSEM) as compared to those in the algebra-based course*. (Research Question 2)

Previous research detailed in Chapter 2 indicates that calculus-based students do outperform algebra-based students on tests of physics conceptual understanding. This study expands on previous research by examining student performance on specific E&M topics.

Hypothesis 5: *Students show a growth in their use and application of the expert model as opposed to, the naïve model on E&M topics after traditional instruction*. (Research Question 2)

Previous research detailed in Chapter 2 indicates that on students show a growth in their use and application of the expert model after instruction on tests covering Newtonian topics. This study expands on previous research because it examines student model use on E&M topics.

Hypothesis 6: *There is a relationship between student understanding about models in science and conceptual understanding of E&M topics*. (Research Question 3)

Previous research as detailed in Chapter 2 indicates that understanding of the nature of science and models in particular, are important to doing and learning science. This study expands on previous research by examining the link between understanding of models (a specific area of the nature of science) and changes in conceptual understanding of E&M topics.

Summary

This quasi-experimental study examines the change in students' views of models in science and the change in performance on a conceptual understanding test on electricity and magnetism topics after a semester-long physics course covering E&M. Both traditional data analysis and an innovative technique called model analysis is used to gain a more detailed picture of how student views about models are related to greater conceptual understanding on E&M topics.

CHAPTER 4 – RESULTS AND DATA ANALYSIS

Introduction

The data collected in this study was quantitative. Two instruments were used to collect the data. One was a 27-item Likert Scale assessment. It assessed Student Understanding of the Use of Models in Science (SUMS). The other was a 32-item multiple-choice test designed to gauge the students' conceptual understanding of a variety of electricity and magnetism topics (CSEM). A copy of these instruments can be found in Appendix A (SUMS) and Appendix B (CSEM). The researcher administered each assessment as both a pre and a post test. The pre-test was given during the first week of the semester; the post test was administered during the second to last week of the semester.

The research questions and data for this study yielded a *2x2 mixed factorial design*. A mixed factorial design is a study with both *between-groups* and *within-subjects* independent variables. The *between-groups* design comes from the *Course* independent variable because each participant is enrolled in only one of the two courses. The two courses are Algebra-based (AB) and Calculus-based (CB). The *within-subjects* design is a result of the *Time* independent variable. The t*ime* independent variable is the "time of measurement" or pre- and post-tests. Each subject in the course experiences the same instruction (no experimental and/or control groups); however, their performance on the assessments (the dependent variable or DV) is compared before and after instruction.

Both the CSEM and SUMS were found to be reliable tests by the test developers (Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001; Treagust, Chittleborough, & Mamiala, 2002) and this researcher through the use of Cronbach's Alpha. A reliable test means that the items have reasonable internal consistency and measure what they purport to measure.

Cronbach's Alpha measures this internal consistency by measuring the degree to which a set of items are interrelated or correlated to each other. Table 5 (below) shows the Cronbach's Alpha for each test. In addition, Cronbach's Alpha is reported for the tests as a whole and for the grouped topics in the CSEM and the themes in SUMS. An α greater than 0.70 is generally considered reasonable; however, a test is considered adequately reliable provided that α is between 0.60 and 0.69.

Table 5 – Reliability Test

		Cronbach's Alpha
CSEM	Complete Test	0.687
	by Topics	0.738
SUMS	Complete Test	0.825
	by Theme	0.621

Research Questions

This dissertation attempts to answer the following three research questions:

1. How does traditional physics instruction in E&M alter students' views of models in science?
2. To what extent does traditional physics instruction in E&M alter students' conceptual understanding of E&M topics?
3. What is the relationship between students' understanding of models in learning and doing science, and conceptual understanding of E&M?

RESEARCH HYPOTHESES

In order to answer the three research questions above, six research hypotheses were examined. They are:

1. Student understanding of models in science would not increase after a traditionally taught physics course covering electricity and magnetism topics. (Research Question 1)

2. After traditional instruction, students enrolled in the calculus-based course will possess a greater understanding of models in science than those students enrolled in the algebra-based course. (Research Question 1)
3. Students' conceptual understanding of E&M topics would improve after a traditionally taught physics course covering electricity and magnetism. (Research Question 2)
4. After traditional instruction, students enrolled in the calculus-based course will have a greater conceptual understanding of E&M topics than those enrolled in the algebra-based course. (Research Question 2)
5. Students show a growth in their use and application of the expert model as opposed to the naïve model on E&M topics after instruction. (Research Question 2)
6. There is a relationship between student understanding of models in science and conceptual understanding of E&M topics. (Research Question 3)

Research Question 1

Research Question 1 was answered by comparing student pre- and post- test performance on each of the five themes assessed on SUMS.

RESEARCH HYPOTHESIS 1

The first research hypothesis was that *student understanding of models in science would not increase after a traditionally taught physics course covering electricity and magnetism topics*. The results of the pre- and post- test are summarized in Table 6 below.

TABLE 6 – Combined SUMS results (n = 106)

	Pre-test		Post-test	
	Mean	Std Dev	Mean	Std Dev
Models as Multiple Representations (MR)	4.079	0.402	3.995	0.468
Models as Exact Replicas (ER)	3.412	0.636	3.338	0.767
Models as Explanatory Tools (ET)	4.298	0.414	4.296	0.445
How Scientific Models are Used (USM)	3.780	0.802	3.969	0.620
The Changing Nature of Scientific Models (CNM)	4.327	0.631	4.261	0.649

Both the algebra-based and calculus-based scores were considered together and a paired-samples t-test was run to compare the mean of the student responses on the five themes identified in the SUMS assessment. The paired-samples t-test was chosen because the one independent variable (time) has two categories (pre and post-test). Time of measurement is the within-subjects independent variable. The samples are paired because the same students took both the pre- and post-test. The only significant difference in pre- and post-test scores at the $\alpha = 0.05$ level for the SUMS assessment was the USM theme. Alpha (α) measures the probability of Type I error or determining that a conclusion is false (rejecting the null hypothesis) when it is in fact true. A significant difference at the $\alpha = 0.05$ level means that there is only a 5% chance of erroneously determining that students showed a significant gain in understanding the use of scientific models because of the instruction. Table 7 below contains the results.

TABLE 7 – SUMS Paired Samples Test

	Sig (2-tailed)
$MR_{pre} – MR_{post}$	0.170
$ER_{pre} – ER_{post}$	0.323
$ET_{pre} – ET_{post}$	0.974
$USM_{pre} – USM_{post}$*	0.024
$CNM_{pre} – CNM_{post}$	0.395

*significant at α = 0.05

RESEARCH HYPOTHESIS 2

In order to address the second research hypothesis, c*alculus-based (CB) students possess a greater understanding of models in science than those students enrolled in the algebra-based (AB) course*, the SUMS results were also analyzed based on the course (AB or CB). Table 8 contains those results.

TABLE 8 – SUMS Results by Course

	Algebra-Based (n = 44)				Calculus-Based (n = 62)			
	Pre-test		Post-test		Pre-test		Post-test	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
MR	4.094	0.406	3.884	0.438	4.068	0.402	4.075	0.477
ER	3.498	0.643	3.472	0.769	3.351	0.629	3.244	0.757
ET	4.386	0.432	4.286	0.461	4.235	0.393	4.303	0.437
USM	3.803	0.955	4.023	0.748	3.763	0.681	3.930	0.513
CNM	4.455	0.631	4.348	0.593	4.237	0.620	4.199	0.684
TOTAL	3.979	0.350	3.903	0.429	3.870	0.310	3.869	0.344

An independent-samples t-test was conducted to determine if the calculus-based students performed significantly better than the algebra-based students. The independent samples test was chosen because it is the appropriate test when examining the between-groups variable. (*Course*, algebra-based and calculus-based, is the between-groups variable.) Each subject is in only one group, either the algebra-based course or the calculus-based course. The results are summarized in Table 9 (below). Normally, when multiple t-tests are used on the same set of data, an analysis of variance must be done to avoid inflated type 1 error. However, since there is no overlap among questions assessing each theme on SUMS, the t-test on each individual theme is on a discrete set of data and the chance of inflated type 1 error is not an issue.

Levene's test for Equality of Variance was used to determine whether or not the variance in the groups was due to chance. If Levene's test is not significant (sig is not less than α or 0.05) then the variances are considered equal or homogenous. However, if Levene's test determines that the variances are significantly different (at the $\alpha = 0.05$ level) then the difference in the performance of the groups as identified by the t-test could be by chance. Therefore, a more stringent criterion must be used in order to determine if the results of the t-test really indicate that the difference is due to the conditions of the study. In this case, it is appropriate to use the *equal variances not assumed* t-test where the degrees of freedom are adjusted downward to take into account the lack of homogeneity of variances. The less homogeneity of variance, the more the degrees of freedom is adjusted. If the difference in the groups is significant even after the variances are assumed not to be equal, then the difference is most likely due to the conditions of the study.

The only significant difference in student performance (at the $\alpha = 0.05$ level) between the algebra-based and calculus-based groups was found in the *Models as Multiple Representations* (MR) theme (sig = 0.038). A sig value of 0.038 for a t-test of Equality of means there is only a 3.8% chance of the difference in the algebra-based and calculus-based student performance being due to chance. In this case, Levene's test for Equality of Variance is not significant (sig = 0.287, 0.287 is not less than alpha or 0.05) and indicates that the variability in the two groups is not significantly different. The results of the independent t-test shows that overall, the calculus-based students did not perform significantly better than the algebra-based students. They did not show a significantly better understanding of models in science. The one exception to this was the MR theme. Students in the calculus-based course showed a significantly greater understanding of models as multiple representations than those in the algebra-based course.

Table 9 – SUMS Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (2-tailed)
MR_{post}	Equal variances assumed	1.146	.287	-2.103	104	.038
	Equal variances not assumed			-2.134	97.288	.035
ER_{post}	Equal variances assumed	.017	.898	1.516	104	.133
	Equal variances not assumed			1.512	91.907	.134
ET_{post}	Equal variances assumed	.049	.826	-.191	104	.849
	Equal variances not assumed			-.189	89.617	.850
USM_{post}	Equal variances assumed	4.683	.033	.757	104	.451
	Equal variances not assumed			.711	70.861	.479
CNM_{post}	Equal variances assumed	.041	.839	1.171	104	.244
	Equal variances not assumed			1.200	99.842	.233

Research Question 2

Research Question 2 was answered by comparing student pre- and post-test performance on the CSEM. In order to answer Research Question 2, three research hypotheses were examined (Research Hypotheses 3, 4 and 5.) The first two used traditional data analysis while the third used Model Analysis (MA) to examine, in detail, the changes in student conceptual understanding of particular E&M topics.

RESEARCH HYPOTHESIS 3

The third research hypothesis was that *student conceptual understanding of E&M topics would improve after a traditionally taught physics course covering electricity and magnetism*. The results of the pre- and post-test are summarized in Table 10 (below).

TABLE 10 – Overall CSEM Results (n = 106)

	Pre-test		Post-test	
	Mean	Std Dev	Mean	Std Dev
Topic 01 (3)	0.248	0.276	0.314	0.290
Topic 02 (3)	0.384	0.229	0.450	0.284
Topic 03 (3)	0.365	0.330	0.528	0.362
Topic 04 (5)	0.264	0.200	0.302	0.205
Topic 05 (5)	0.269	0.173	0.327	0.204
Topic 06 (2)	0.118	0.235	0.094	0.219
Topic 07 (5)	0.166	0.180	0.200	0.193
Topic 08 (4)	0.123	0.199	0.340	0.279
Topic 09 (2)	0.151	0.277	0.425	0.364
Topic 10 (4)	0.182	0.160	0.224	0.195
Topic 11 (4)	0.182	0.203	0.245	0.246
TOTAL (32)	0.244	0.099	0.319	0.133

Number of questions for each topic in parenthesis

As indicated for the SUMS assessment, both the CSEM algebra-based and calculus-based scores were considered together and a paired-samples t-test was run to compare performance on the overall mean and the mean of the eleven topics identified in the CSEM assessment. The paired-samples t-test was chosen because the one independent variable (time) has two categories (pre and post-test). Time of measurement is the within-subjects independent variable. The samples are paired because the same students took both the pre- and post-test. A significant difference performance at the $\alpha = 0.05$ level in was found for the overall CSEM performance and on the following seven topics: Topics 1, 2, 3, 5, 8, 9, and 11. Table 11 (below) contains the results. (See Table 4 in Chapter 2 for a list of topics.)

The results of the paired sample t-test indicated that students did show a significant gain in conceptual understanding of electricity and magnetism topics after instruction. In particular, the gains were significant for the following topics: *Charge Distribution on Conductors/Insulators* (Topic 1); *Coulomb's Force Law* (Topic 2); *Force Caused by an Electric Field* (Topic 4); *Work, Electric Potential, Field and Force* (Topic 5); *Magnetic Field Caused by* *a Current* (Topic 8); *Magnetic Field Superposition* (Topic 9); and *Newton's Third Law* (Topic 11).

TABLE 11 – CSEM Paired-Samples t-test results

	Sig (2-tailed)
$\text{MEAN}_{pre} - \text{MEAN}_{post}$*	0.000
$\text{T01}_{pre} - \text{T01}_{post}$*	0.050
$\text{T02}_{pre} - \text{T02}_{post}$*	0.038
$\text{T03}_{pre} - \text{T03}_{post}$*	0.000
$\text{T04}_{pre} - \text{T04}_{post}$	0.173
$\text{T05}_{pre} - \text{T05}_{post}$*	0.023
$\text{T06}_{pre} - \text{T06}_{post}$	0.387
$\text{T07}_{pre} - \text{T07}_{post}$	0.176
$\text{T08}_{pre} - \text{T08}_{post}$*	0.000
$\text{T09}_{pre} - \text{T09}_{post}$*	0.000
$\text{T10}_{pre} - \text{T10}_{post}$	0.072
$\text{T11}_{pre} - \text{T11}_{post}$*	0.029

*significant at $\alpha = 0.05$

RESEARCH HYPOTHESIS 4

In order to examine the fourth research hypothesis, *the calculus-based students would show greater conceptual understanding on E&M topics than the algebra-based students*, the CSEM results were also analyzed based on the course (algebra-based or calculus-based). Table 12 (below) contains those results.

TABLE 12 – CSEM Results by Topics

	Algebra-Based (n = 44)				Calculus-Based (n = 62)			
	Pre-test		Post-test		Pre-test		Post-test	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Topic 01 (3)	0.523	0.731	0.909	0.802	0.903	0.863	0.968	0.923
Topic 02 (3)	1.091	0.676	1.227	0.711	1.194	0.698	1.436	0.934
Topic 03 (3)	0.909	0.936	1.296	1.091	1.226	1.015	1.790	1.042
Topic 04 (5)	1.523	1.110	1.682	1.006	1.629	1.271	1.903	1.364
Topic 05 (5)	1.500	1.131	1.705	1.025	1.694	0.968	2.145	1.329
Topic 06 (2)	0.182	0.390	0.114	.0321	0.274	0.518	0.242	0.502
Topic 07 (5)	0.849	0.805	0.864	0.878	0.823	0.967	1.097	1.020
Topic 08 (4)	0.341	0.526	1.091	0.984	0.597	0.931	1.548	1.169
Topic 09 (2)	0.159	0.370	0.727	0.660	0.403	0.639	0.936	0.765
Topic 10 (4)	0.659	0.568	1.023	0.849	0.774	0.688	0.807	0.721
Topic 11 (4)	0.682	0.708	0.773	0.912	0.758	0.881	0.855	1.143
TOTAL (32)	6.89	2.264	9.07	3.372	8.44	3.565	11.02	4.661

Number of questions for each topic in parenthesis

An independent-samples t-test was conducted to determine if the calculus-based students performed significantly better than the algebra-based students. The independent samples test was chosen because the between-groups design was tested. Each subject is in only one group, either the algebra-based course or the calculus-based course. See Table 13 (below).

The independent-samples t-test indicated that overall, students in the calculus-based course performed significantly better (at the $\alpha = 0.05$ level) than students in the algebra-based course (sig = 0.014). The test also indicated that students in the calculus-based course scored significantly better (at the at $\alpha = 0.05$ level) for both CSEM Topic 3, *Electric Force and Field Superposition*, (sig = 0.020) and Topic 8, *Magnetic Field Caused by a Current* (sig = 0.032). For Topic 3, Levene's test of equality of variance (sig = 0.807, 0.807 is not less than α or 0.05) indicated that the variability in the two courses is not significantly different. For the overall mean and Topic 8, Levene's test of equality of means was significant (The mean sig = 0.010 and the Topic 8 sig = 0.030. In these two cases, the value for significance is less than α or 0.05.) A significant result from Levene's test indicated that the scores from the calculus-based course and the algebra-based course were significantly different and this difference could be by chance. A more stringent criterion, equal variances not assumed, must be used to determine if the difference was by chance or due to the treatment. However, even using this more stringent test, the calculus-based students significantly out-performed the algebra-based students both overall (sig = 0.014) and on Topic 8, (sig = 0.032). Students in the calculus-based course significantly outperformed students in the algebra-based course on their overall understanding of electricity and magnetism and on two specific topics, *Magnetic Field Caused by a Current* (Topic 8) and *Electric Force and Field Superposition* (Topic 3).

Table 13 – CSEM Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (2-tailed)
MEAN_{post}	Equal variances assumed	6.801	.010	-2.366	104	.020
	Equal variances not assumed			-2.497	103.948	.014
T01_{post}	Equal variances assumed	.881	.350	-.340	104	.734
	Equal variances not assumed			-.348	99.724	.728
T02_{post}	Equal variances assumed	7.319	.008	-1.244	104	.216
	Equal variances not assumed			-1.302	103.453	.196
T03_{post}	Equal variances assumed	.060	.807	-2.363	104	.020
	Equal variances not assumed			-2.344	90.114	.021
T04_{post}	Equal variances assumed	4.297	.041	-.914	104	.363
	Equal variances not assumed			-.962	103.816	.338
T05_{post}	Equal variances assumed	4.978	.028	-1.844	104	.068
	Equal variances not assumed			-1.926	103.230	.057
T06_{post}	Equal variances assumed	9.793	.002	-1.492	104	.139
	Equal variances not assumed			-1.603	103.028	.112
T07_{post}	Equal variances assumed	.815	.369	-1.227	104	.223
	Equal variances not assumed			-1.259	100.058	.211
T08_{post}	Equal variances assumed	4.834	.030	-2.117	104	.037
	Equal variances not assumed			-2.180	100.911	.032
T09_{post}	Equal variances assumed	.257	.613	-1.460	104	.147
	Equal variances not assumed			-1.497	100.030	.138
T10_{post}	Equal variances assumed	.005	.943	1.414	104	.160
	Equal variances not assumed			1.375	82.946	.173
T11_{post}	Equal variances assumed	.900	.345	-1.855	104	.066
	Equal variances not assumed			-1.890	98.355	.062

RESEARCH HYPOTHESIS 5

The fifth research hypothesis was that *students will show a growth in their use and application of the expert model as opposed to the naïve model on E&M topics after instruction.* Eight of the eleven themes studied to answer this question were chosen because the expert, naïve and null models could be easily identified and mapped to the multiple choice answers on the CSEM. The topics are:

- Coulomb's Law (Topic 2)
- Electric Force and Field Superposition (Topic 3)
- Force Caused by an Electric Field (Topic 4)
- Work, Electric Potential, Field and Force (Topic 5)
- Induced Charge and Electric Field (Topic 6)
- Magnetic Field Caused by a Current (Topic 8)
- Magnetic Field Superposition (Topic 9)
- Newton's Third Law (Topic 11)

Model Analysis

The fifth research hypothesis was answered using a new data analysis technique called Model Analysis (MA). MA uses quantum physics ideas and mathematics to analyze student thinking. It assumes that just as two seemingly contradictory states coexist in the quantum world (light behaves as a particle and a wave in quantum physics), students can possess seemingly contradictory models of physical processes. The analogy between student model use and the behavior of a particle is explained in more detail Chapter 2. MA assumes that students possess competing, contradictory mental models and they often apply them inconsistently. MA also gives researchers information about the level of confusion present in students (CadwalladerOlsker, 2009).

Developed by Lei Bao for his doctoral thesis, MA was offered as an alternative to factor analysis because factor analysis is based on scores, not the models students use. Factor analysis only evaluates the consistency of student answers and does not take into account the fact that students are not consistent in their application of mental models while solving physics problems. Factor analysis is designed to discover relationships among many variables by reducing the large number of (observed) variables to a smaller number of underlying or unobserved “factors.” It estimates the strength of the influence each factor has on the dependent variables. If the goal of the study is to determine which factors have more or less influence or the amount of influence a set of factors might have, factor analysis is the tool. However, it does not provide information on the type of incorrect responses a student may choose as does MA. Just as with other statistical methods, with MA it is important to have a large population; in general, as the size of the population increases, the uncertainty in the results decreases (Bao, 1999; Bao, Hogg, & Zollman, 2002; Bao & Redish, 2001).

Briefly, the models students use are identified, mapped to the choices on the CSEM, and combined through the process explained below to produce the class density matrix. Eigenvalue decomposition of the class density matrix is used to reveal the class model state. Below is a list of the important terms, and their definitions, used in model analysis:

Class Model Density Matrix (or Class Density Matrix) – A matrix that is obtained by combining the *student model state vectors*; it contains information about the models that the class is using to solve a set of questions on a particular topic.

Consistent Model State – The students consistently use one of the common models (expert, naïve or null) in answering all the questions on a particular topic.

Density Matrix – In quantum physics, a matrix that contains the probability that a particle will occupy a certain state. In MA, a matrix that contains the probability that a student will use a certain model to solve a set of questions on a particular topic.

Inconsistent Model State (Mixed Model State) – The students use different models to solve questions on a particular topic.

Model Plot – A two-dimensional graph used to represent student usage of the two dominant models (expert and naïve) (Bao, 1999).

Model Space – A mathematical representation of the probability that a student will use a particular model.

Model State – The term used to describe what models a student is using to solve problems.

Operator – A mathematical instruction to do “something” to the function that follows.

Probability Amplitude – The square root of the probability that a particle will occupy a certain state. Probability amplitudes instead of the actual probabilities are combined during mathematical operations in quantum mechanics.

Probability Vector – A single column matrix that contains the *student model state* (the probability that a student will use a particular model to answer questions on a particular topic.)

State Vector – In quantum physics, a vector that gives the probability amplitude that particles will be in their various possible states. In MA, a vector that gives the probability amplitude that students will use particular models to solve problems.

Student Model Density Matrix – A matrix that contains information about the models that a student is using to solve a set of questions on a particular topic.

Student Model State Vector (Student Model State) – Analogous to the wave function, it is the vector that represent how a student responds (the models they use) to answer a set of questions on a particular topic. The elements of the Student Model State Vector are the probability amplitudes associated with the student's responses.

Vector – A mathematical construct with both magnitude and direction. In quantum physics, the elements of a vector represent the state of a particle. In mathematics, vectors are represented as $\vec{A}$ or $\vec{B}$. In quantum physics, vectors are functions and are represented in Dirac notation by $|u_k\rangle$ or $|\psi\rangle$ called "kets."

Wave Function – In quantum physics, a function that describes the state (amplitude) of a particle. It contains all the information that can be known about the particle. When squared, it represents the intensity of the particle which is the probability that a particle will be in a particular region at a particular time. In model analysis, a function that describes student model use and when squared, gives the probability that the student will use a particular model at a particular time.

The Process of Model Analysis

This section will take the reader through the process of model analysis step-by-step by analyzing student results on the CSEM for Newton's Third Law of Motion. The next sub-section contains a table (Table 14) that details the notations used for the equations in the model analysis.

Table 14 – Symbols Used in Model Analysis

Symbol	Description
k	Student index
N	Total number of students
m	Total number of questions in the topic/concept group
w	Total number of models (expert, novice, null)
r_k	Student response vector for the k^{th} student
u_k	Student model response vector for the k^{th} student
$P_{\eta\mu}$	An element of D
D_k	Student model density matrix for the k^{th} student
D	Class model density matrix (sum of D_k)
V	Student model vector matrix – Eigenvector matrix of D
λ_μ	The μ^{th} eigenvalue of D
$v_{\mu\eta}$	An element of V

IDENTIFICATION AND MAPPING OF STUDENT MODELS

The first step is to identify the most common models used by students. The naïve models most likely used by students are identified through an examination of physics education research and are identified in Chapter 2. For Newton's Third Law, the models are also detailed below:

Expert Model: two different (equal but opposite) forces act on two different bodies whether they are in contact or at a distance. (The Expert model is referred to as Model 1 for clarity in the mathematical operations and representations.)

Naïve Model: two opposite forces acting on the same body whose magnitudes are influenced by the size or charge of the bodies. (The Naïve model is referred to as Model 2 for clarity in the mathematical operations and representations.)

Null Model: incorrect or other irrelevant ideas. (The Null model is referred to as Model 3 for clarity in the mathematical operations and representations.)

These models are then mapped to the multiple choice response options (A – E) for the corresponding questions on the CSEM. Newton's Third Law is addressed in questions 4, 5, 7 and 24. Table 15 (below) details the response options and the corresponding models most likely used by students choosing those options.

Table 15 – Misconceptions for Newton's Third Law

	Question 4	Question 5	Question 7	Question 24
Model 1 (Expert)	B	C	B	C
Model 2 (Naïve)	A & D	D	A & C	B & D
Model 3 (Null)	C & E	A, B, & E	D & E	A & E

Computing the Student Model Density Matrix

Next, using the information above, each student's responses for the questions were mapped to vectors. Vectors are used because student model use is analogous with a particle in quantum theory and vectors "are the vehicles of choice for quantum theory" (Polkinghorne, 2002). For example, student *k* responded to questions 4, 5, 7 and 24, with D, C, E, and D respectively. That is, the student used the naïve model for questions 4 and 24, the correct model for question 5, and a null model for question 7. The responses produce four vectors $(0, 1, 0)^T$, $(1, 0, 0)^T$, $(0, 0, 1)^T$ and $(0, 1, 0)^T$. These vectors are summed to get an overall model response vector for the student which is $(1, 2, 1)^T$. It is written using equation 1 as follows where the subscript numbers 1, 2 and 3 are the corresponding models (expert, novice and null):

$$r_k = \begin{pmatrix} n_{1k} \\ n_{2k} \\ n_{3k} \end{pmatrix} \qquad \text{Equation 1}$$

For student *k*, the student response vector is: $r_k = \begin{pmatrix} 1 \\ 2 \\ 1 \end{pmatrix}$.

Equation 2 is used to compute the probability amplitude and normalize the student response vector (r_k) to produce the *student model vector* $(|u_k\rangle)$. The student response vector is normalized in order to account for the number of questions; thus ensuring that the probabilities will add up to one.

$$u_k = \begin{pmatrix} u_{1k} \\ u_{2k} \\ u_{3k} \end{pmatrix} = \frac{1}{\sqrt{m}} \begin{pmatrix} \sqrt{n_{1k}} \\ \sqrt{n_{2k}} \\ \sqrt{n_{3k}} \end{pmatrix} = |u_k\rangle \qquad \text{Equation 2}$$

Where m = number of questions for the topic or concept group.

For the k^{th} student, the *student model vector* is: $|u_k\rangle = \frac{1}{\sqrt{4}} \begin{pmatrix} \sqrt{1} \\ \sqrt{2} \\ \sqrt{1} \end{pmatrix} = \frac{1}{2} \begin{pmatrix} 1 \\ \sqrt{2} \\ 1 \end{pmatrix}$.

The next step is to calculate the *student model density matrix* for the k^{th} student using matrix multiplication. The *student model density matrix* is a matrix that contains information about the models students use to solve problems. The *student model vector* is analogous to the wave function. In quantum physics, the wave function gives the probability amplitude of a particle. By definition, squaring the wave function yields the particle's intensity and the particle's intensity is equivalent to the probability that a particle will be in a particular place at a particular time (Serway, Moses, & Moyer, 2005). Similarly, when the *student model vector* is squared, the result is the *student model density matrix* which gives the probability that a student will use a particular model at a particular time. See Equation 3:

$$D_k = |u_k\rangle\langle u_k| = \frac{1}{m} \begin{bmatrix} n_{1k} & \sqrt{n_{1k}n_{2k}} & \sqrt{n_{1k}n_{3k}} \\ \sqrt{n_{2k}n_{1k}} & n_{2k} & \sqrt{n_{2k}n_{3k}} \\ \sqrt{n_{3k}n_{1k}} & \sqrt{n_{3k}n_{2k}} & n_{3k} \end{bmatrix} \qquad \text{Equation 3}$$

For the k^{th} student, the *student model density matrix* is: $D_k = \frac{1}{4}\begin{pmatrix} 1 & \sqrt{2} & 1 \\ \sqrt{2} & 2 & \sqrt{2} \\ 1 & \sqrt{2} & 1 \end{pmatrix}$.

Table 16 (below) is a list of several *student model density matrices*. The data are taken from the CSEM post-test. The topic is Newton's Third Law of Motion and the students were chosen randomly. There were four questions per topic (m = 4) and there are three possible models, expert, naïve and null (w = 3).

Table 16 – Samples of *Student Model Density Matrices*

Student Model Responses	Student Response Vector (r_k)	Student Model Vector (U_k)	Student Model Density Matrix (D_k)
(121)	$\begin{pmatrix} 1 \\ 2 \\ 1 \end{pmatrix}$	$\frac{1}{2}\begin{pmatrix} 1 \\ \sqrt{2} \\ 1 \end{pmatrix}$	$\frac{1}{4}\begin{pmatrix} 1 & \sqrt{2} & 1 \\ \sqrt{2} & 2 & \sqrt{2} \\ 1 & \sqrt{2} & 1 \end{pmatrix}$
(400)	$\begin{pmatrix} 4 \\ 0 \\ 0 \end{pmatrix}$	$\frac{1}{2}\begin{pmatrix} 2 \\ 0 \\ 0 \end{pmatrix}$	$\frac{1}{4}\begin{pmatrix} 4 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$
(103)	$\begin{pmatrix} 1 \\ 0 \\ 3 \end{pmatrix}$	$\frac{1}{2}\begin{pmatrix} 1 \\ 0 \\ \sqrt{3} \end{pmatrix}$	$\frac{1}{4}\begin{pmatrix} 1 & 0 & \sqrt{3} \\ 0 & 0 & 0 \\ \sqrt{3} & 0 & 3 \end{pmatrix}$

COMPUTING THE CLASS MODEL DENSITY MATRIX

The *class model density matrix* gives detailed information about the models students use to solve problems. "In general, the diagonal elements (P_{11}, P_{22}, P_{33} from Equation 4 below) give the distribution of the probability of students using the different physical models, while the off-diagonal elements (P_{12}, P_{13}, P_{23}, etc. from Equation 4 below) indicate consistency of the students' using their models" (Bao, 1999).

$$D = \begin{bmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{bmatrix} \qquad \text{Equation 4}$$

Another way to think about it is that the "diagonal elements are the probabilities of correct matches between responses and student model-states while the off-diagonal elements represent the "cross talk" [or noise] from mismatched model-states and responses" (Bao, 1999). Note that the off-diagonal elements are not probabilities but "one way of expressing correlations between probabilities" (Bao & Redish, 2004). This means that larger diagonal elements imply a more consistent use of the three models while larger off-diagonal elements represent more confusion or inconsistencies in student thinking. In quantum theory, "the superposition principle permits the mixing together of states that classically would be immiscible" (Polkinghorne, 2002). As a result, probabilities cannot just be added as they would in traditional statistics because "things that were mutually distinct possibilities are entangled with each other quantum mechanically" (Polkinghorne, 2002). The calculation of the off-diagonal elements (essentially the non-communitive property of row by column matrix multiplication) takes this "mixing" into account.

It is important to note that Bao (1999) used several techniques to verify the accuracy and reliability of the data. He found that in a vast majority of the cases, the uncertainty associated with student guessing does not "significantly degrade the results." He determined that as long as the number of students is significantly larger than the number of models (N >> w), the probability of error due to guessing is minimized to the point that it does not affect the results of the calculations. In this study, the N of 106 is significantly larger than the number of models which in this case is three.

THE MEANING OF THE CLASS MODEL DENSITY MATRIX

As stated earlier, the purpose of MA is to analyze data that cannot be examined using traditional statistics. Factor analysis and other data analysis techniques look at the consistency of student results and not the implications of the students' wrong answers. The *class model density matrix* stores information about student choices for the topic or concept group. It was named the *Density Matrix* because in quantum physics, the density matrix describes the statistical state of a quantum system. As noted previously, the way students use models when solving physics problems can be thought of as a quantum system. The diagonal elements of the *Class Model Density Matrix* (P_{11}, P_{22}, P_{33} from Equation 4 above) are the probabilities of how the class uses the different models. Since they are the probabilities of the use of the three models, and the students use only one of the three models (expert, naïve, null), they add to one. The off-diagonal elements (P_{12}, P_{13}, P_{23}, etc. from Equation 4 above) are not probabilities, but rather represent the correlation between the probabilities. They are the cross-talk or noise that represents the confusion in student application of the models. Table 17 (below) gives examples of the three "typical model conditions for a class of students" (Bao, 1999).

Table 17 – Samples of *Class Model Density Matrices*

$\begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$	$\begin{pmatrix} 0.5 & 0 & 0 \\ 0 & 0.3 & 0 \\ 0 & 0 & 0.2 \end{pmatrix}$	$\begin{pmatrix} 0.5 & 0.2 & 0.1 \\ 0.2 & 0.3 & 0.1 \\ 0.1 & 0.1 & 0.2 \end{pmatrix}$
A Consistent One-Model	B Consistent Three-Model	C Inconsistent Three-Model

(Bao, 1999)

Sample A is a case where all students have the same physical model. In this situation, they all have and apply the expert model (Model 1) on a set of questions covering a particular topic. They do not use any other models and thus there is no "noise" or confusion as to how they apply the expert model. Sample B shows that the class uses all three models but applies them consistently, without confusion (no "noise") when answering a set of questions on a particular topic. If this model presents itself, the researcher can assume that the students possess all three models (expert, naïve, and null) but applies them consistently in given situations. Sample C is the most common situation and the one that is overwhelmingly prevalent in this study. Here, students inconsistently apply all three physical models. Situations B and C have the same diagonal elements but different off-diagonal (P_{12}, P_{13}, P_{23} etc.) elements. This implies that just looking at the diagonal elements does not give enough information about how the students apply the models they have (Bao, 1999). It does not tell the researcher if the students are using the models consistently or inconsistently. The next section addresses that issue.

EVALUATING THE CLASS MODEL DENSITY MATRIX

Because analyzing the diagonal elements does not provide enough information, eigenvalues and eigenvectors of the matrices are used. In order to understand the role of eigenvalues and eigenvectors, it is important to understand what an *operator* is as it relates to quantum physics. In very general terms, an operator is something that transforms one state into another state. Recall that a *state* is in very simple terms, the description of the situation. In MA, the state is the description of student responses. The *class density matrix* is the description or state that contains the probabilities of using models 1, 2 and 3 on the diagonals and some numbers (off-diagonal entries) that represent the confusion students' exhibit as they apply those models to solve problems. In order to make sense of the *class density matrix*, the confusion must be taken into account along with the probability of applying a certain model. In other words, it is important to know how much the confusion of the models affects the probability of applying each model. An eigenvalue is an operator that transforms the state of the *class density matrix* into a state, described as the eigenvector that combines the probability of applying a certain model with the amount of confusion that exists.

The eigenvalues and eigenvectors of the *class density matrix* are calculated by eigenvalue decomposition. Eigenvalue decomposition is just the mathematical process of re-writing or "breaking down" the original matrix into eigenvalues and their associated eigenvectors. The eigenvalues and eigenvectors give information about the level of confusion that exists in the class and the similarity of the models used by students. If a majority of students have the same model state, one large, primary eigenvalue will be obtained and the associated eigenvector will be indicative of the model state of the majority of the class. An eigenvalue is considered large if it is greater than 0.80. If the primary eigenvalue is small (less than 0.65) it indicates that the student model states are mixed and that class of students has and uses a wide variety of models. An eigenvalue below 0.40 indicates that there is no dominant student model. The next section contains the eigenvalue and eigenvector decomposition for the study.

CALCULATING THE STUDENT MODEL STATES

Tables 18 and 19 are the results of the eigenvalue and eigenvector decomposition from *Class Model Density Matrix* on the CSEM for Topic 11, Newton's Third Law of Motion. This data is used to create the model plots. Table 18 contains the overall results for Topic 11 and Table 19 consists of the data divided by course, algebra-based and calculus-based. The data for the other topics can be found later in this chapter.

Table 18 – Overall CSEM Results for Newton's Third Law of Motion (Topic 11)

		Density Matrix	**Eigen value**	**Eigen vector**		
				v1	**v2**	**v3**
Topic 11	**Pre**	0.18 0.20 0.09	0.78	0.34	0.70	0.63
		0.20 0.50 0.28	0.06	0.78	-0.59	0.23
		0.09 0.28 0.31	0.15	0.53	0.42	-0.74
	Post	0.20 0.17 0.06	0.18	-0.78	-0.31	0.55
		0.17 0.49 0.27	0.74	-0.11	-0.79	-0.60
		0.06 0.27 0.30	0.08	0.62	-0.53	0.58

Table 19 – By Course CSEM for Newton's Third Law of Motion (Topic 11)

		Algebra-Based					Calculus-Based				
		Density Matrix	**Eigen value**	**Eigen vector**			**Density Matrix**	**Eigen value**	**Eigen vector**		
				v1	**v2**	**v3**			**v1**	**v2**	**v3**
Topic 11	**Pre**	0.17 0.20 0.10	0.81	0.33	-0.70	0.64	0.19 0.20 0.08	0.77	0.34	0.65	0.68
		0.20 0.50 0.31	0.13	0.77	-0.20	-0.61	0.20 0.51 0.27	0.07	0.79	-0.59	0.16
		0.10 0.31 0.32	0.05	0.55	0.69	0.47	0.08 0.27 0.29	0.15	0.50	0.48	-0.72
	Post	0.19 0.19 0.08	0.74	-0.35	-0.76	0.55	0.21 0.16 0.05	0.20	-0.84	-0.46	-0.28
		0.19 0.53 0.23	0.10	-0.82	0.53	0.21	0.16 0.46 0.30	0.06	-0.10	0.64	-0.76
		0.08 0.23 0.26	0.15	-0.45	-0.38	-0.81	0.05 0.30 0.33	0.75	0.53	-0.61	-0.58

In the case of Newton's Third Law of Motion, the primary eigenvalue for the data as a whole, and by course, are between the upper and lower limits described above (between 0.80 and 0.65) so the eigenvalue decomposition will give a good picture of the class's model use. The data are plotted in the next section.

MODEL PLOTS

As noted earlier, students usually have two dominant models that they use to solve problems. Those are the expert model and the naïve model. In order to visually represent those models, a two-dimensional plot called a *model plot*, is constructed. The model plot allows researchers to graphically represent student model use including the types of models students use, the consistency which they use them, and the probabilities for students and the class to use the different models (Bao & Redish, 2004). When pre- and post-test results are plotted on the same graph, changes or the lack of changes in student model use are obvious. Figure 2 is a model plot with the important regions labeled. A description of the each region follows. After the regions are explained, the data from Newton's Third Law are plotted. An explanation of what the plots show is included.

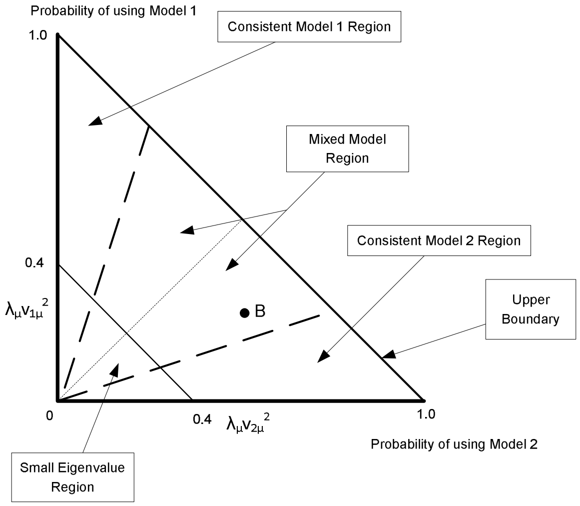

Figure 2 – Regions on a Model Plot

As noted above, the model plot is a two-dimensional graph that visually illustrates the models used by students to solve questions covering a specific topic. The horizontal axis is the probability of using model 2 (the naïve model) while the vertical axis is the probability of using model 1 (the expert model.) Since the graph is of the probabilities of using a certain model and probabilities do not exceed one, the x and y maxima are both one. As a result, the line $x + y = 1$ between the points (1,0) and (0,1) is the uppermost boundary of the plot. A class model state with a large eigenvalue (a dominant model used) will be close to that line. Whereas, a class with a small eigenvalue (no dominant model used) will be close to the origin.

The graph is also divided into four regions. They are: Consistent Model 1 (bounded by the vertical axis and the lines $y = 3x$, $x + y = 0.4$ and $x + y = 1$), Consistent Model 2 (bounded by the horizontal axis and the lines $y = \frac{1}{3}x$, $x + y = 0.4$ and $x + y = 1$), Mixed Model (bounded by the lines $y = 3x$, $y = \frac{1}{3}x$, $x + y = 1$ and $x + y = 0.4$), and Small Eigenvalue (bounded by the horizontal and vertical axis but below the line $x + y = 0.4$.) When the point representing the *class model state* is located in the Consistent Model 1 (or Consistent Model 2) region, it means that the students in the class have a similar and consistent model state and a high probability of applying Model 1 (or Model 2). When the point is located in the Mixed Model region, it indicates that although students have a dominant model, they are inconsistent in applying the models to solve problems. If the point is above the line $y = x$, then the students apply model 1 more frequently and if it is below the line $y = x$, the students tend toward model 2. Finally, if the point is located in the Small Eigenvalue region, it indicates that there is no dominant model and students are inconsistent in the application of the models. This can be considered the pre-naïve state of model use.

The *class model state* is plotted on the graph; it is Point B on Figure 1, above. The point represents the probability that a student in the class will use the corresponding models when answering questions on a specific topic. The vertical component (y-coordinate) of the point is $P_1 = \lambda_\mu {v_{1\mu}}^2$ and the horizontal component (x-coordinate) is $P_2 = \lambda_\mu {v_{2\mu}}^2$. The coordinates of B are (P_2, P_1) or ($\lambda_\mu {v_{2\mu}}^2$, $\lambda_\mu {v_{1\mu}}^2$). These coordinates for all topics can be found in Appendix C, Table 23.

Newton's Third Law of Motion data are used to further explain the model plots. Figure 3, below, is a model plot of the pre- and post-test *class model density matrices* for overall (algebra-based and calculus-based data combined) student performance. Figures 4 and 5 are the model plots for *Newton's Third Law* separated by course, algebra-based (AB) or calculus based (CB). In all plots "1" is the pre-test point, "2" is the post-test point, and the arrow indicates the magnitude and direction of the change in student model use. A discussion of what the plots indicate follows the graphs.

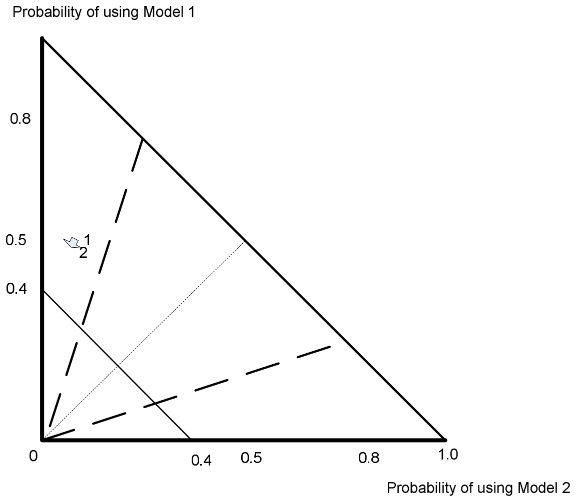

Figure 3 – *Newton's Third Law of Motion* Overall Student Performance Model Plot

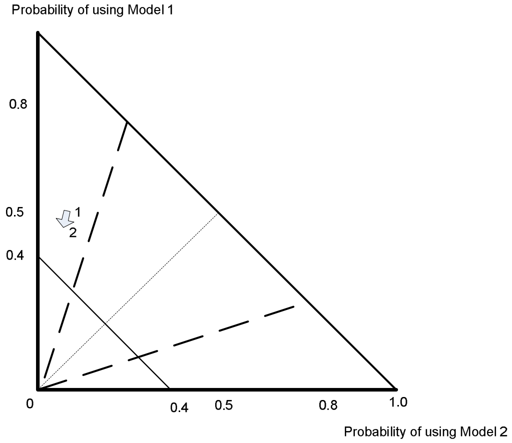

Figure 4 – *Newton's Third Law of Motion* CB Student Performance Model Plot

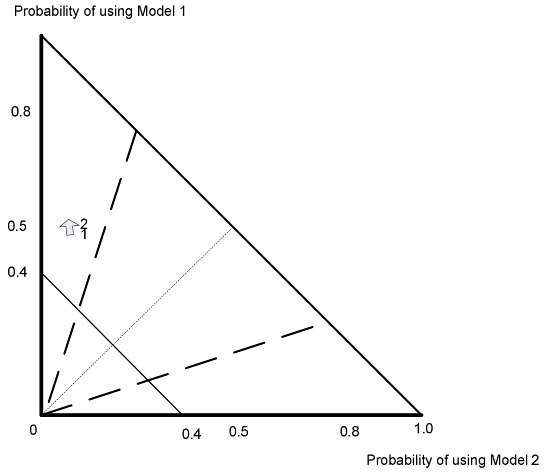

Figure 5 – *Newton's Third Law of Motion* AB Student Performance Model Plot

In all three cases above (CB, AB, and AB/CB combined) there is little or no changes in the models students use to solve Newton's Third Law problems. In all three cases, the students are predominantly using the expert model both before and after instruction.

Data for CSEM Topics

The data for the topics chosen to investigate Research Hypothesis five, *students will show growth in their use and application of the expert model as opposed to the naïve model on E&M topics after instruction*, are included in Tables 20 and 21. They are listed overall and separated by course. The data are plotted in the next section.

Table 20 – Overall CSEM Results

		Density Matrix	**Eigen value**	**Eigen vector**		
				v1	**v2**	**v3**
Topic 2	**Pre**	0.38 0.18 0.26	0.73	-0.67	-0.70	-0.27
		0.18 0.22 0.12	0.09	-0.38	0.63	-0.68
		0.26 0.12 0.39	0.17	-0.64	0.35	0.69
	Post	0.44 0.14 0.26	0.73	0.72	-0.52	0.47
		0.14 0.18 0.10	0.12	0.30	0.84	0.46
		0.26 0.10 0.38	0.16	0.63	0.19	-0.75
Topic 3	**Pre**	0.36 0.09 0.20	0.66	-0.59	0.80	0.13
		0.09 0.21 0.15	0.20	-0.36	-0.40	0.84
		0.20 0.15 0.42	0.13	-0.72	-0.45	-0.52
	Post	0.53 0.11 0.16	0.65	0.84	-0.52	-0.12
		0.11 0.16 0.09	0.23	0.27	0.22	0.94
		0.16 0.09 0.31	0.11	0.46	0.82	-0.33
Topic 4	**Pre**	0.26 0.22 0.25	0.86	0.48	-0.85	-0.22
		0.22 0.31 0.31	0.08	0.57	0.12	0.82
		0.25 0.31 0.42	0.05	0.67	0.52	-0.54
	Post	0.31 0.21 0.27	0.82	0.55	-0.74	-0.39
		0.21 0.26 0.25	0.09	0.50	-0.08	0.86
		0.27 0.25 0.41	0.07	0.66	0.67	-0.32
Topic 5	**Pre**	0.27 0.24 0.25	0.86	0.51	-0.86	-0.10
		0.24 0.34 0.30	0.07	0.59	0.26	0.76
		0.25 0.30 0.37	0.05	0.63	0.45	-0.64
	Post	0.32 0.26 0.25	0.85	0.56	-0.69	0.46
		0.26 0.31 0.27	0.08	0.57	-0.07	-0.82
		0.25 0.27 0.35	0.05	0.59	0.72	0.35
Topic 8	**Pre**	0.12 0.12 0.06	0.09	-0.97	-0.20	0.17
		0.12 0.65 0.23	0.78	0.11	-0.90	-0.43
		0.06 0.23 0.23	0.13	0.23	-0.40	0.89
	Post	0.34 0.25 0.13	0.75	0.56	-0.81	0.13
		0.25 0.45 0.20	0.15	0.72	0.41	-0.56
		0.13 0.20 0.21	0.10	0.40	0.41	0.82
Topic 9	**Pre**	0.15 0.07 0.03	0.14	-0.97	-0.14	0.19
		0.07 0.62 0.13	0.67	0.08	-0.95	-0.31
		0.03 0.13 0.22	0.18	0.23	-0.28	0.93
	Post	0.42 0.15 0.07	0.58	0.71	-0.70	-0.05
		0.15 0.38 0.09	0.25	0.65	0.68	-0.35
		0.07 0.09 0.20	0.16	0.28	0.22	0.93

Table 21 – CSEM Results by Topic and Course

		Algebra-Based					Calculus-Based				
		Density Matrix	**Eigen value**	**Eigen vector**			**Density Matrix**	**Eigen value**	**Eigen vector**		
				v1	**v2**	**v3**			**v1**	**v2**	**v3**
Topic 2	**Pre**	0.36 0.19 0.23	0.69	0.67	-0.73	0.13	0.40 0.17 0.29	0.78	0.67	0.65	-0.37
		0.19 0.27 0.09	0.08	0.44	0.53	0.72	0.17 0.19 0.14	0.09	0.35	-0.71	-0.61
		0.23 0.09 0.36	0.22	0.60	0.43	-0.68	0.29 0.14 0.41	0.13	0.66	-0.27	0.70
	Post	0.41 0.20 0.25	0.74	0.70	-0.71	0.10	0.46 0.09 0.26	0.72	0.73	-0.65	-0.22
		0.20 0.25 0.13	0.10	0.44	0.53	0.73	0.09 0.13 0.07	0.17	0.19	-0.12	0.97
		0.25 0.13 0.33	0.16	0.57	0.46	-0.68	0.26 0.07 0.41	0.11	0.66	0.75	-0.03
Topic 3	**Pre**	0.30 0.11 0.17	0.68	-0.47	0.88	0.09	0.41 0.07 0.22	0.67	0.67	-0.74	0.10
		0.11 0.27 0.21	0.19	-0.50	-0.35	0.79	0.07 0.17 0.11	0.20	0.25	0.34	0.91
		0.17 0.21 0.42	0.12	-072	-0.33	-0.61	0.22 0.11 0.42	0.13	0.70	0.58	-0.41
	Post	0.43 0.12 0.15	0.62	0.72	-0.68	-0.17	0.60 0.11 0.17	0.70	0.90	-0.43	-0.12
		0.12 0.22 0.12	0.24	0.39	0.19	0.90	0.11 0.12 0.07	0.20	0.22	0.18	0.96
		0.15 0.12 0.35	0.14	0.58	0.71	-0.40	0.17 0.07 0.27	0.09	0.39	0.89	-0.25
Topic 4	**Pre**	0.25 0.21 0.25	0.85	0.48	0.63	-0.61	0.27 0.22 0.24	0.86	0.49	-0.84	-0.25
		0.21 0.34 0.30	0.08	0.58	-0.75	-0.32	0.22 0.30 0.31	0.09	0.56	0.08	0.82
		0.25 0.30 0.41	0.07	0.66	0.20	0.72	0.24 0.31 0.42	0.04	0.67	0.54	0.51
	Post	0.28 0.22 0.30	0.88	0.53	0.83	0.18	0.33 0.21 0.25	0.80	0.57	-0.69	-0.44
		0.22 0.28 0.28	0.05	0.51	-0.14	-0.85	0.21 0.25 0.23	0.11	0.50	-0.13	0.86
		0.30 0.28 0.44	0.07	0.68	-0.54	-050	0.25 0.23 0.40	0.07	0.65	0.71	-0.27
Topic 5	**Pre**	0.25 0.23 0.22	0.85	0.47	-0.86	0.19	0.28 0.25 0.27	0.87	0.53	0.78	-0.34
		0.23 0.36 0.32	0.08	0.62	0.17	-0.76	0.25 0.32 0.29	0.05	0.57	-0.62	-0.54
		0.22 0.32 0.37	0.04	0.63	0.47	0.62	0.27 0.29 0.38	0.06	0.63	-0.09	0.77
	Post	0.28 0.26 0.27	0.89	0.53	-0.75	-0.40	0.34 0.26 0.24	0.81	0.60	0.61	-0.51
		0.26 0.31 0.31	0.06	0.57	-0.04	0.82	0.26 0.30 0.24	0.09	0.57	0.13	0.81
		0.27 0.31 0.38	0.03	0.63	-0.66	-0.41	0.24 0.24 0.32	0.06	0.57	-0.78	-0.28
Topic 8	**Pre**	0.09 0.11 0.06	0.07	-0.97	-0.17	0.15	0.15 0.13 0.06	0.75	0.23	-0.94	0.26
		0.11 0.68 0.25	0.81	0.09	-0.90	-0.43	0.13 0.63 0.21	0.11	0.90	0.10	-0.43
		0.06 0.25 0.24	0.13	0.21	-0.41	0.89	0.06 0.21 0.22	0.13	0.38	0.33	0.86
	Post	0.27 0.23 0.12	0.76	0.46	-0.88	0.08	0.38 0.26 0.14	0.75	0.62	-0.77	0.11
		0.23 0.51 0.22	0.13	0.78	0.37	-0.51	0.26 0.41 0.18	0.14	0.68	0.47	-0.56
		0.12 0.22 0.22	0.10	0.42	0.30	0.86	0.14 0.18 0.20	0.10	0.38	0.42	0.82
Topic 9	**Pre**	0.08 0.05 0.03	0.07	0.99	0.09	0.10	0.20 0.09 0.03	0.64	0.21	-0.94	-0.27
		0.05 0.67 0.15	0.72	-0.05	0.95	-0.31	0.09 0.59 0.12	0.18	0.94	0.27	-0.21
		0.03 0.15 0.25	0.20	-0.12	0.31	0.94	0.03 0.12 0.20	0.16	0.27	-0.21	0.94
	Post	0.36 0.17 0.08	0.59	0.63	-0.62	-0.48	0.45 0.13 0.06	0.59	-0.72	0.69	0.11
		0.17 0.42 0.07	0.22	0.73	0.68	0.08	0.13 0.35 0.11	0.30	-0.63	-0.66	-0.65
		0.08 0.07 0.22	0.18	0.27	-0.40	0.88	0.06 0.11 0.19	0.10	-0.28	-0.29	0.76

Model Plots of CSEM Data

The fifth research hypothesis was that *students would show a growth in their use and application of the expert model as opposed to the naïve model on E&M topics after instruction*. Model Plots are used to address this research hypothesis. Again, the results of this study are mixed. The model plot is designed to show the class's primary model state. When the pre- and post-test are plotted on the same graph, changes (or lack of changes) in the class's model state are evident. As seen above, on the whole the classes are using the expert model when solving *Newton's Third Law of Motion* problems (Topic 11).

Topic 2 (*Coulomb's Law*)

The model plots for Topic 2 (*Coulomb's Law*) show little or no change in student model use after instruction. Figure 6 is the plot for overall student performance. The plots for the calculus-based and algebra-based courses are very similar and can be found in Appendix C, Figures 13 and 14. The plot shows that students remain in the naïve region but border the mixed and low eigenvalue region. This means that there is no dominant model used by the majority of the class to solve *Coulomb's Law* problems.

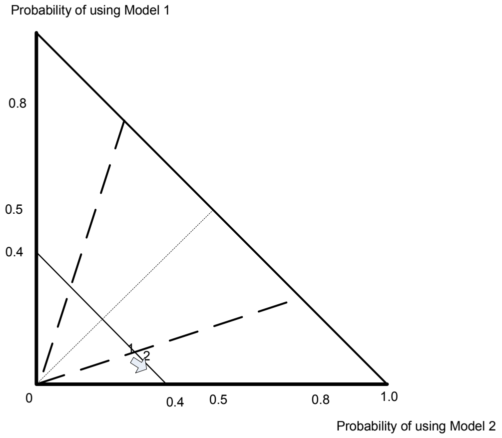

Figure 6 – Topic 2 (*Coulomb's Law*) Overall Student Performance Model Plot

Topic 3 (*Electric Force and Field Superposition*)

The model plots for Topic 3 (*Electric Force and Field Superposition*) indicate that there is no dominant model used by the class prior to instruction, but after instruction students in both classes use the naïve model to solve electric force and field superposition problems. Figure 7 is the model plot for overall student performance. The plots for the calculus-based and algebra-based course are very similar and can be found in Appendix C, Figures 15 and 16.

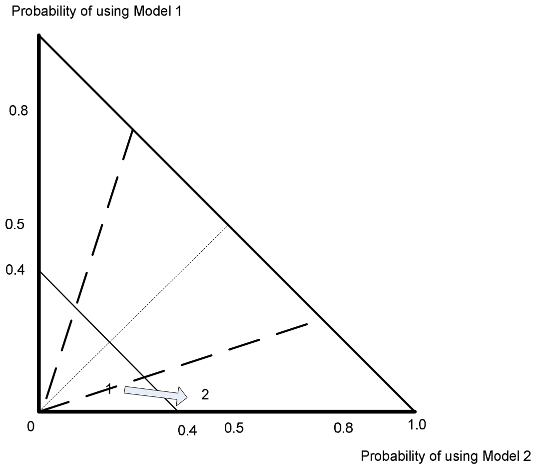

Figure 7 – Topic 3 (*Electric Force and Field Superposition*)
Overall Student Performance Model Plot

Topic 4 (*Force Caused by an Electric Field*) & Topic 5 (*Work, Electric Potential, Field & Force*)

The model plots for Topic 4 (*Force Caused by an Electric Field*) and Topic 5 (*Work, Electric Potential, Field & Force*) are very similar. Both show that the class uses mixed models to solve problems from these categories both before and after instruction. Figure 8 is the model plot for overall student performance for Topic 4 and Figure 9 is the model plot of overall student performance for Topic 5. The plots for the calculus-based and algebra-based course for both topics are very similar and can be found in Appendix C, Figures 17 – 20.

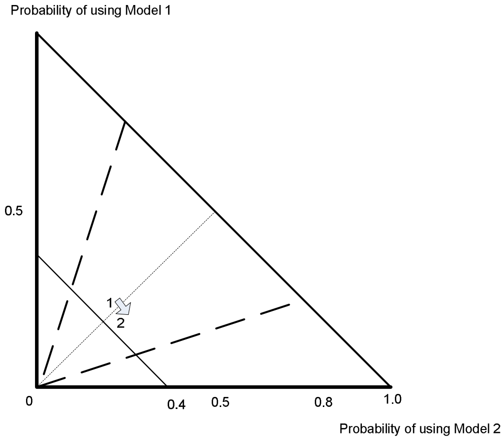

Figure 8 – Topic 4 (*Force Caused by an Electric Field*)
Overall Student Performance Model Plot

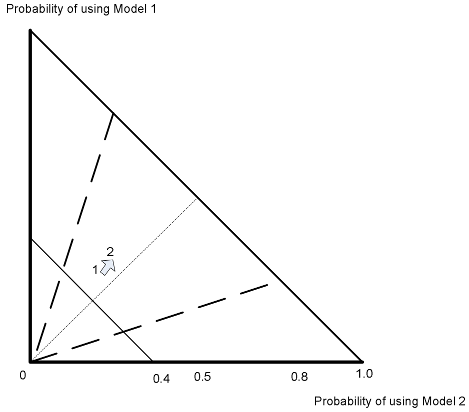

Figure 9 – Topic 5 (*Work, Electric Potential, Field & Force*)
Overall Student Performance Model Plot

Topic 8 (*Magnetic Field Caused by a Current*) & Topic 9 (*Magnetic Field Superposition*)

The model plots for Topic 8 (*Magnetic Field Caused by a Current*) and Topic 9 (*Magnetic Field Superposition*) show more dramatic results. Figure 10 is the model plot for overall student performance for Topic 8 and Figure 11 is the model plot of overall student performance for Topic 9. A description follows the plots. The plots for the calculus-based and algebra-based course for both topics are very similar and can be found in Appendix C, Figures 21 – 24.

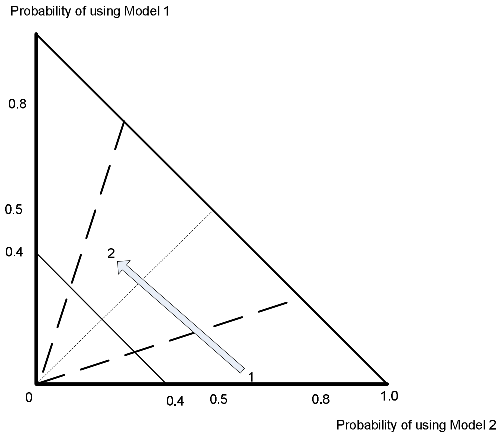

Figure 10 – Topic 8 (*Magnetic Field Caused by a Current*)
Overall Student Performance Model Plot

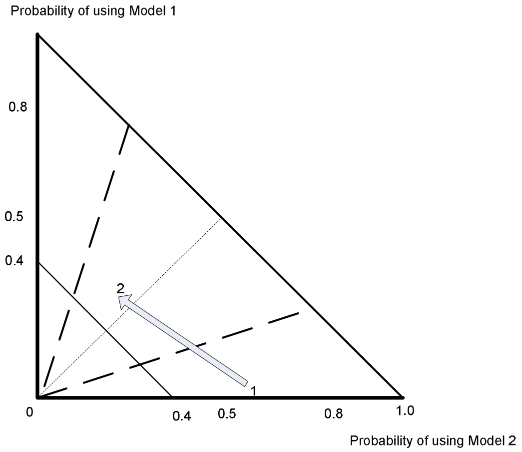

Figure 11 – Topic 9 (*Magnetic Field Superposition*)
Overall Student Performance Model Plot

In all six cases for topics 8 and 9, the students' model usage moved from the naïve model region to the mixed model region. In addition, the post-test data indicates that the students are in the upper region of the mixed model region, above the line y = x. This means that after instruction, students are beginning to abandon the naïve model and are beginning to apply the expert model to solve problems related to *magnetic field caused by a current and magnetic field superposition*. Students are now mixing the expert and naïve model to solve the problems; whereas, before instruction, students were almost exclusively using the naïve model.

Research Question 3

Research Question 3 was answered by examining post-test results from both SUMS and CSEM. One research hypothesis was examined.

RESEARCH HYPOTHESIS 6

The sixth research hypothesis was that *there is a relationship between student understanding of models in science and conceptual understanding of E&M topics*. The eleven topics covered in the CSEM and the CSEM mean were correlated with the five themes surveyed in SUMS. A significant relationship was determined at the $\alpha = 0.05$ level. The nine pairs identified in Table 22 (below) demonstrated a significant relationship.

Models as Exact Replicas (ER) was significantly correlated with the most topics in CSEM. The only other significant correlation was *Models as Multiple Representations* (MR) and CSEM Topic 6: *Induced Charge and Electric Field*.

TABLE 22 – Correlation of CSEM and SUMS

	SUMS ER *(models as Exact Replicas)*		SUMS MR *(models as Multiple Representations)*	
CSEM mean	r	-0.372		
	Sig (2-tailed)	0.000		
CSEM topic 2 *(Coulomb's Force Law)*	r	-0.245		
	Sig (2-tailed)	0.011		
CSEM topic 3 *(Electric Force and Field Superposition)*	r	-0.240		
	Sig (2-tailed)	0.013		
CSEM topic 4 *(Force caused by an Electric Field)*	r	-0.230		
	Sig (2-tailed)	0.018		
CSEM topic 5 *(Work, Electric Potential, Field and Force)*	r	-0.251		
	Sig (2-tailed)	0.009		
CSEM topic 6 *(Induced Charge and Electric Field)*	r	-0.238	r	0.213
	Sig (2-tailed)	0.014	Sig (2-tailed)	0.028
CSEM topic 8 *(Magnetic Field Caused by a Current)*	r	-0.221		
	Sig (2-tailed)	0.023		
CSEM topic 9 *(Magnetic Field Superposition)*	r	-0.230		
	Sig (2-tailed)	0.018		

The implications of all of these results are discussed in the next chapter, Chapter 5.

CHAPTER 5 – DISCUSSION AND CONCLUSIONS

Introduction

The purpose of this study is to examine changes in student knowledge about models in science, and changes in their conceptual understanding of electricity and magnetism (E&M). This chapter discusses the results of the examination of three research questions. It also includes a discussion of the results with regard to instruction, as well as questions for further study.

Summary of the Study

The results of this study indicate that without instruction about models in science, students do not show significant improvement in their understanding of scientific models. This occurs even after studying E&M, which requires the extensive use of models. The results also show that student-conceptual understanding of E&M topics *does* significantly improve after a course in E&M, and *after such a course*, students show increased sophistication in how they solve some E&M conceptual questions. Finally, the results indicate that there is a relationship between student conceptual understanding on selected E&M topics and student understanding of models in science.

The results are discussed in detail in the next sections.

Research Question 1

Research Question 1, *how does traditional physics instruction in E&M alter students' views of models in science*, was answered by the examination of two research hypotheses. The data were obtained using the Likert-scale survey instrument, Student-Understanding of Models in Science (SUMS).

RESEARCH HYPOTHESIS 1

The first research hypothesis was that *student understanding of models in science would not increase after a traditionally taught physics course covering E&M topics*. It was supported by this research with one exception. Overall, student understanding of models in science did not significantly change. This was expected because previous research shows that if there is no instruction in the nature of science, student understanding of the nature of science does not improve (Fishwild, 2005). Previous research did not specifically address student understanding of models in science. Therefore, this study offers more specificity by providing evidence that traditional instruction does not impact student views of models in science.

However, when the five themes (*Models as Multiple Representations, Models as Exact Replicas, Models as Explanatory Tools, The Use of Scientific Models, and The Changing Nature of Models*) are considered individually, students showed a statistically significant increase ($\alpha = 0.05$) in understanding in one theme: the *Use of Scientific Models* (USM). No previous study identified this growth in student understanding. A probable explanation is that E&M is a very abstract part of physics. Arons (1997), points out that physicists construct abstract models that rationalize the observed effects of "non-contact interactions that involve energy transfers through acceleration of objects, through deflections against opposing forces, or through thermal effects." He goes on to say that conceptual understanding is even further beyond reach because the understanding of concepts such as potential difference, electric current, Lorentz force, field strength, and more is built on top of the abstract models. Teachers refer to, and use these models extensively to help students grasp the abstract concepts and gain some understanding of E&M topics.

RESEARCH HYPOTHESIS 2

The second research hypothesis was that *calculus-based students would show a greater understanding of models in science*. The data did not support this hypothesis with one exception. The one theme where calculus-based student understanding was significantly higher than algebra-based students was for the *Models as Multiple Representations* (MR) theme. The difference was statistically significant at the $\alpha = 0.05$ level. This indicates that, in general, calculus-based student views of models in science are not any more advanced than those in the algebra-based course.

The fact that the calculus-based students did not show a more sophisticated understanding of models in science than the algebra-based students in all themes is surprising in that the calculus-based students are in the calculus-based course because they are majoring in science or engineering fields while the algebra-based students are not. However, a detailed examination of the SUMS MR questions provides an explanation as to why the calculus-based students outperformed the algebra-based students in the MR theme. Science majors (in this case the calculus-based students) historically have stronger mathematical skills and higher science achievement on science conceptual assessments (Ding, Chabay, Sherwood, & Beichner, 2006; Halloun & Hestenes, 1985; Hestenes & Wells, 1992; Hestenes, Wells, & Swackhamer, 1992; Laws, 1991; Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001) and three of the MR questions lean toward an understanding of mathematical models. Since the calculus-based students have higher mathematical skills, it is not surprising that they demonstrate more sophisticated thinking about mathematical models. For example, question three states “models can show the relationship of ideas clearly.” Simple equations show relationships clearly and those with better mathematical skills are more likely to see these relationships in the formulas.

As noted previously, no previous studies documented the correlation or lack of correlation between student conceptual understanding of physics concepts and their understanding of models. This relationship is explored in Research Question Three, (*what is the relationship between students' understanding of models in science and their conceptual understanding of E&M*) later in this chapter.

Research Question 2

Research Question 2, *to what extent does traditional physics instruction in E&M alter students' conceptual understanding of E&M topics*, was answered by the examination of three research hypotheses. The data were obtained from the Conceptual Survey of Electricity and Magnetism (CSEM), a multiple choice assessment.

RESEARCH HYPOTHESIS 3

The third research hypothesis was that *student conceptual understanding of E&M topics would improve after a traditionally taught course covering E&M topics*. While this seems obvious for overall test performance, there remained some doubt about how students would perform on individual concept groups or topics. The data confirmed that as expected, students' overall scores were significantly improved at the $\alpha = 0.05$ level from the pre-test to the post-test. In addition, they showed statistically significant gains on most of the individual topics examined. Those topics are:

- Charge Distribution on Conductors/Insulators (Topic 1)
- Coulomb's Force Law (Topic 2)
- Electric Force and Field Superposition (Topic 3)
- Work, Electric Potential, Field & Force (Topic 5)
- Magnetic Field Caused by a Current (Topic 8)

- Magnetic Field Superposition (Topic 9)
- Newton's Third Law (Topic 11)

However, their scores did not significantly improve on four of the eleven topics. Those topics are:

- Force Caused by an Electric Field (Topic 4)
- Induced Charge & Electric Field (Topic 6)
- Magnetic Force (Topic 7)
- Faraday's Law (Topic 10)

The research on student learning of these topics is thin. Much of the research refers to the basic topics and how students learn those topics. For example, Topics 2, 3, 5 and 11 are related to concepts students either learn in first physics course that covers Newtonian concepts or have everyday experiences with. Specifically, they require knowledge of force, work, and simple vector operations. Topic 1 is concerned with the definitions and simple questions concerning conductors and insulators. Finally, students have some prior experience with magnetic fields from elementary and middle school science. Misconceptions and details about these topics are addressed in Chapter Two of this dissertation.

What is not addressed in the research is how students apply and combine these ideas to solve more complex problems. The four topics where students did not show significant improvement are the most abstract topics. They require a much deeper understanding of the models and how to mentally manipulate them (Seab, 2009). For example, Topic 3 (*Electric Force and Field Superposition*) covers two charges and their interaction, while Topic 4 (*Force Caused by an Electric Field*) requires an understanding of electric force, field and vector operations. Student difficulties with vector operations were noted in Chapter 2. In Topic 4, there is only one charge and the elusive “field” is causing the force, a much more abstract situation. Topic 3 is more concrete; there are two charges acting on each other. The issue is further complicated by the misconception that objects at a distance cannot exert a force on each other. Here, another “object” does not exist; the “entity” exerting the force is the field.

This study indicated that *Faraday’s Law* (Topic 10) is another concept where students did not show significant improvement after a course in E&M. In this case, there is some research that might explain this finding. Allain (2001), documented that students show a poor understanding of the concept of rate of change with regards to electric potential. In addition, it is well documented that, in general, students struggle with the concept of rate of change and in particular, those concepts that require an understanding of and application of the mathematical concept of rate of change (Meredith, 2008; Thompson, 1994; Yerushalmy, 1997). To answer Faraday’s Law questions correctly, students must understand the rate of change of magnetic flux because the induced electric field depends on the change of the magnetic flux.

Again, research on why student failed to show improvement on Topic 6 (*Induced Charge and Electric Field*) is limited. One possible explanation is that unlike early physics textbooks, modern textbooks (and thus physics instructors) pay minimum attention to the topic of induced charge (Seab, 2009).

Finally, Topic 7 (*Magnetic Force*) also presented a problem for students even after instruction. This study documented that students demonstrated no significant improvement in understanding the topic. The possible reasons for this are a bit harder to pin down given the data from this study. More research is needed to determine why students showed significant improvement in their understanding of Topics 3, 8 and 9 (*Electric Force and Field Superposition, Magnetic Field Caused by a Current, and Magnetic Field Superposition*) and not

Topic 7 (*Magnetic Force*). One possible reason is that students still possess lingering confusion between electric and magnetic properties or retain persistent misconceptions of force from their Newtonian course. Another possible explanation is related to mathematics and vector operations. Students struggle with the right hand rule and cross products. In fact, algebra-based students do not usually encounter this in their mathematics courses prior to taking physics (Seab, 2009).

RESEARCH HYPOTHESIS 4

The fourth research hypothesis was that *after traditional instruction, calculus-based students would out-perform algebra-based students on the CSEM*. Here again, the results are mixed. The data indicate that as expected, the calculus-based students did score significantly better than the algebra-based students on the CSEM. However, when the individual concept groups are examined separately, the calculus-based students only significantly (α = 0.05) level outperformed the algebra-based students on two topics. The topics are:

- Electric Force and Field Superposition (Topic 3)
- Magnetic Field Caused by a Current (Topic 8)

In general, this study confirms the previous research that indicates calculus-based students significantly outperform algebra-based students on tests of conceptual development on various physics topics (Force Concept Inventory, Mechanics Baseline Test, Brief Electricity & Magnetism Assessment, CSEM). However, it is interesting that when each topic is examined separately, calculus-based students only show significant gains over the algebra-based students in two topics listed above. The CSEM questions covering the topics were conceptual and did not require the use of mathematics so mathematical skill appears not to be the underlying reason. One potential area of exploration is the correlation between each of these topics and the SUMS theme, *Models as Exact Replicas* (ER). The correlation of CSEM topics and SUMS themes is addressed in Research Question 3.

RESEARCH HYPOTHESIS 5

The fifth research hypothesis was that *students show a growth in their use and application of the expert model as opposed to the naïve model on E&M topics*. This study documented that with regard to some CSEM topics, students did show an increase in sophistication of their model use. Each topic will be addressed below.

Topic 2 (*Coulomb's Law*)

The model plots for Topic 2 indicate that prior to instruction the students as a whole do not use a dominant model to solve *Coulomb's Law* problems. They seem to be in the pre-naïve state when it comes to model use. Bao and Redish (2004) define the pre-naïve state as having no model or conception of the concept. This is to be expected since students receive little or no instruction in Coulomb's Law prior to the E&M course. However, after instruction, there is little or no change in student model use. The very slight change in model use is toward the naïve model but both the pre- and post-test model points are clustered together near the intersection of the low eigenvalue, naïve, and mixed region. When viewed in conjunction with the paired samples t-test results, a contradiction is evident. Although the students showed significant improvement (at the $\alpha = 0.05$ level) on Coulomb's Law questions from the pre-test to the post-test, they did not show growth in their conceptual understanding of the topic. In other words, they can solve the problems more effectively, but do not demonstrate growth toward using or attaining the expert model.

Topic 3 (*Electric Force and Field Superposition*)

The model plots for Topic 3 indicate that prior to instruction the students as a whole do not use a dominant model to solve problems covering *electric force and field superposition*. Again, this is to be expected since students receive little or no instruction in *electric force and field superposition* prior to the E&M course. In this case, the post-test results show a more pronounced movement from the pre-naïve state toward the class's use of the naïve model than *Coulomb's Law* problems. Again, students showed significant improvement in problem-solving ability (at the $\alpha = 0.05$ level) from the pre- to the post-test but did not demonstrate movement toward the acquisition of the expert model.

Topic 4 (*Force Caused by an Electric Field*)

The model plots for Topic 4 show that both the pre- and post-test class model states are clustered close together near the middle of the mixed model region. This means that the dominant model-state for the class is the mixed model-state. After instruction, students showed virtually no change in the use of the expert model. They continued to use mixed models to solve *force caused by an electric field* problems. Interestingly, the pre- and post-test correlation was not significant at the $\alpha = 0.05$ level which indicates that students did not show significant improvement in correct answers to Topic 4 questions either. One possible explanation is that students enter the course with some knowledge of force, hence the mixed model use. However, the concept of electric fields, which is new, is difficult for students. Little or no change in model use seems to indicate that they failed to incorporate the new knowledge adequately.

Topic 5 (*Work, Electric Potential, Field & Force*)

The model plots for Topic 5 show that the subjects are employing mixed models to solve *work, electric potential, field and force* problems both before and after instruction. Little or no growth in model use occurred after instruction. Since both *work* and *force* are topics the students have experience with from a previous course, it is not unexpected that they would demonstrate some expert reasoning when solving those problems. However, more research is necessary to determine if this is the case. As noted in Chapter 2, electric potential is a difficult topic conceptually for students and this model plot indicates that students do not show growth in the use of the expert model after instruction even though they show a significant increase (at the $\alpha = 0.05$ level) in correct answers to Topic 5 questions.

Topic 8 (*Magnetic Field Caused by a Current*) & Topic 9 (*Magnetic Field Superposition*)

The model plots for Topic 8 and Topic 9 show the most growth in student conceptual development from pre-test to post-test. It should be noted that the improvement from pre- to post-test was also found to be significant at the $\alpha = 0.05$ level. For both topics, the *class model state* was in the naïve region prior to instruction and after instruction, the *student model state* improved through the mixed region. This is an obvious growth in sophistication of student model use. In Chapter 2, the misconceptions students possess about magnetism were noted. Misconceptions include confusing magnetic properties with electrical properties and difficulty understanding field lines. With these topics, traditional instruction was very effective in developing student conceptual understanding. It is obvious that students entered the course with robust misconceptions, and left the course with a better understanding of the topic. Although they are not using the expert model exclusively, and are still using mixed models to solve problems, they do show that they know the expert model and apply it often. The challenge for instructors is to determine the contexts which trigger the use of the expert and naïve models and help students apply the expert model in all circumstances.

Topic 11 (*Newton's Third Law of Motion*)

The final topic examined using Model Analysis was Topic 11. The model plots for Topic 11 indicate that the classes' dominate model used for solving *Newton's Third Law* problems was the expert model. This is contrary to what Bao (1999) found when he used model analysis on traditional instruction covering Newtonian physics. Bao and Redish (2004) noted that in traditionally taught courses, student model use moved from the naïve region to the mixed model region. They did not find that the students ended the course with an expert view of Newton's Third Law as this study would suggest. A possible reason for the discrepancy is that the *Newton's Third Law* problems as they apply to E&M were more straightforward applications of the Law when compared to the questions on the Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992) which was used in Bao's study. It is important to note that even though the *class model state* showed little change and was in the expert region both before and after instruction, there was a significant improvement (at the $\alpha = 0.05$ level) in student scores on Topic 11 questions from the pre-test to the post-test. This indicates that students were using the expert model both before and after instruction and showed better scores on the assessment items (solved physics problems better) after instruction.

Research Question 3

Research Question 3, *what is the relationship between students' understanding of models in science and their conceptual understanding of E&M*, was answered by the examination of one research hypothesis. The data were obtained from both the Conceptual Survey of Electricity and Magnetism (CSEM), a multiple choice assessment and the Student Understanding of Models in Science, a Likert-scale assessment.

RESEARCH HYPOTHESIS 6

The final research hypothesis was that *there is a relationship between student understanding of models in science, and student conceptual understanding of E&M topics*. This study pointed out numerous correlations that were significant at the α = 0.05 level. Although correlation does not establish causal connection, future exploration of these relationships may be a valuable tool in improving both conceptual understanding in physics and student views of models in science. This study showed a significant relationship between one SUMS theme (*Models as Exact Replicas*), and seven CSEM topics (*Coulomb's Force Law, Electric Force and Field Superposition, Force caused by an Electric Field, Work, Electric Potential, Field and Force, Induced Charge and Electric Field, Magnetic Field caused by a Current, and Magnetic Field Superposition*) The same SUMS theme, *Models as Exact Replicas*, is also correlated with the overall student performance on the CSEM (CSEM mean score). This indicates that the extent to which students view models as exact replicas of reality is important and is related to their conceptual understanding of E&M topics. In other words, the less students view models as exact replicas of reality, the better perform on the conceptual assessment of E&M topics. This is consistent with the scientists' view of models as dynamic constructs that are not necessarily exact or complete but contain the characteristics necessary to examine a particular condition.

One other relationship was uncovered by this study. *Induced Charge and Electric Field* (CSEM Topic 6) and *Models as Multiple Representations* (SUMS MR Theme) were significantly correlated at the α = 0.05 level. This means that whether students view models as a way to show different perspectives is related to their conceptual understanding of *induced charge and electric field*. The difficulties students seem to have with CSEM Topic 6 are related to their poor understanding of conductors, in particular, the shielding effect of conductors (Maloney, 1985;

Maloney, O'Kuma, Hieggelke, & VanHeuvelen, 2001). As a result, several SUMS MR theme questions seem related. In particular, the questions of greatest interest are those that examine if a model can show a relationship clearly and if it has what is needed to explain a scientific phenomenon. Students who perform poorly on these questions most likely do not have adequate models to address the scientific phenomenon. The models most commonly seen in textbooks and thus, student models, are of spheres with small pluses and minuses on the surface. Depending on the situation, the charges are shown on one side or spread over the sphere. The confusion comes in when the charges "move" from one location to another. For example, when students see a neutral conductor whose electrons are repelled by a charged rod, they visualize "a wave" of electrons moving throughout the conductor. Their model does not account for the fact that the attraction of charged bodies can be caused by mobile negative charge, mobile positive charge, or the mobility of both simultaneously (Arons, 1997).

One of the goals of this study is to determine if relationships such as the ones listed above (CSEM Topic 6 and the SUMS MR theme etc.) exist. Further research should examine the exact nature of, and the causal connections of, these relationships. One way to examine the nature of the relationship is to further probe student knowledge of conductors with a larger number of questions whose distractors are carefully selected to match the common misconceptions.

Implications for Instruction

These results have implications for instruction. According to researchers, students generally move through several stages of conceptual development as they learn and use models (Bao, Hogg, & Zollman, 2002; Bao & Redish, 2001, 2004). Figure 11 below illustrates the basic stages.

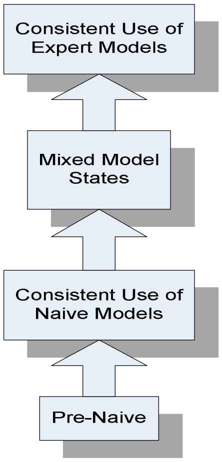

Figure 12 – Stages of Conceptual Development
(Bao & Redish, 2004)

Researchers (Clement, Brown, & Zeitsman, 1989) point out that students learn best when instructors provide opportunities and experiences needed to build upon students' existing mental schema. MA gives instructors valuable knowledge about where the students are in their reasoning. Students do not learn content and instructors do not learn how to help students learn content from listening to a recitation of correct answers memorized explanations. Students learn best when they are led to confront their misconceptions and contradictory ideas (Arons, 1997). In a large university physics course, instructors are often not able to question students individually to determine what inconsistencies in their reasoning are present; therefore, another method must be used. MA allows instructors to gain an accurate picture of the *class model state*, and tailor instruction to meet the needs of the students. Valuable class time can be spent providing opportunities for students to move through the stages of conceptual development shown above. For example, if students are using the naïve model, instructors can help students understand the expert model and provide opportunities for students to see the conflicts in the naïve model. For students in the mixed model-state, instructors must realize that student model use is context dependent (Bao & Redish, 2004). Therefore, instruction should focus on providing examples that conflict with student models and help them compare their reasoning when faced with different situations.

In summary, even though traditional instruction has been shown to be inadequate in reaching many of the goals of educators related to improving student conceptual understanding and student understanding of models in science, this study proved that in many situations, it can be effective in improving student learning. This study indicates that in order to improve the impact of traditional instruction, instructors must ask questions specifically designed to examine student conceptual understanding and then, pay careful attention to the wrong answers given by students to these questions. Additionally, in order to provide students with an authentic education or in other words, an authentic view of science, instructors must spend time teaching students about the nature of science and specifically about models in science.

Additional Implications

This is the first study where MA is used to examine changes in student model use for E&M topics. Researchers (Bao, 1999; Bao, Hogg, & Zollman, 2002; Bao & Redish, 2001) have established MA as a valuable data analysis tool to examine student learning of Newtonian concepts but the data analysis tool has not been widely applied to other topics. In fact, only one other study has used MA to examine anything other than Newtonian physics topics. That study successfully examined the proof schemes held by students (CadwalladerOlsker, 2009) . Consequently, this study further establishes MA as a valid and viable method of data analysis by demonstrating that MA yields information about how students use models to solve E&M problems. It shows the changes in student model-states before and after instruction and relates those model-state changes to significant changes in performance on a test of E&M conceptual development.

It is also important to note that although a significant increase in CSEM scores did not always correspond to movement in model use (Topic 2 – *Coulomb's Law*), the converse is true. In each case where students showed growth in the sophistication of their model use (Topics 8 and 9 – *Magnetic Field caused by a Current* and *Magnetic Field Superposition*) there was a significant improvement in scores on the CSEM. This is consistent with Elby's (1999) finding that doing well in physics courses and trying to understand physics well are two different goals that require different methods of learning. With a goal of improving student conceptual understanding, not just scores on a test, attention to the models students use is prudent. Careful attention to the models students use along with targeted instruction to improve their model use is a way to overcome some of the inadequacies of traditional instruction noted in Chapter 1.

Further Research Questions Raised by this Study

This study was conducted at one university with a limited number of physics students. Therefore, care must be taken when generalizing to all physics students. However, the students at this university are considered representative of the population of physics students enrolled in calculus-based and algebra-based physics courses at other universities because the pre-requisites to enroll in physics at this university were similar to the pre-requisites for university physics at institutions across the country. Therefore, the findings of this study can be used to guide further research. Several questions for further study are noted in the following paragraphs.

The most important area of exploration raised by this study is the examination of the nature of the relationship between *student views of models* in science and their *conceptual understanding of electricity and magnetism*. In particular, special attention should be paid to *student views of models as exact replicas* because this topic is related to numerous electricity and magnetism topics. In addition, the relationship between CSEM Topic 6 (*Induced Charge and Electric Field*) and the SUMS themes *Models as Multiple Representations* (MR).

Although this study established a link between student understanding of models in science and their conceptual development of E&M topics, it has raised many more questions. One in particular, is related to the finding through Model Analysis that CSEM Topics 8 and 9 (*Magnetic Field caused by a Current* and *Magnetic Field Superposition*) showed the greatest improvement in student model use, yet Topic 7 (*Magnetic Force*) showed no improvement in model use or correlation with any SUMS theme. (Topic 9, *Magnetic Field Superposition* is correlated to SUMS theme, *Use of Scientific Models* or USM.)

Other questions raised by this study are as follows:

- Why do students show a significant improvement in CESM Topics 3, 8 and 9 (*Electric Force and Field Superposition, Magnetic Field caused by a Current,* and *Magnetic Field Superposition*) but not Topic 7 (*Magnetic Force*)?
- Does the relationship between the two CSEM topics above (Topics 3 and 8) and the SUMS ER Theme (*Models as Exact Replicas*) have any significance? Similarly, does the lack of the relationship between the SUMS ER Theme and the other CSEM topics have any significance?
- Why do calculus-based students perform significantly better than algebra-based students in only two (Topic 3, *Electric Force and Field Superposition* and Topic 8, *Magnetic Field Caused by a Current*) of the eleven CSEM topics or alternately, is this an anomaly due to the size or composition of the sample population?

- What is the relationship between prior knowledge of *work and force* and expert model attainment on the electricity and magnetism topics of *Work, Electric Potential, Field and Force?*
- What are the fundamental differences between student knowledge about CSEM Topics 8 and 9 (*Magnetic Field Caused by a Current* and *Magnetic Field Superposition*) and the other CSEM topics that did not show such a profound change in model use? In addition, what is it about traditional physics instruction on those topics that has such a profound affect on student model use?

Conclusion

The results of this study suggest that without specific instruction on the use of models in science, overall understanding of how models are used in science does not improve after a traditional electricity and magnetism course. Additionally, this study demonstrated that not only does student conceptual understanding of electricity and magnetism topics improve after a traditionally taught electricity and magnetism course, but also, students demonstrate more sophistication in their understanding of some electricity and magnetism topics. In the latter case, students showed improvement in their application of the expert rather than the naïve or null model on select electricity and magnetism topics. Finally, this study established a relationship between student conceptual understanding of electricity and magnetism topics and their understanding of models in science. Further research is needed to determine the nature of the correlation. However, now that this link has been established, future studies can be designed to examine the relationship in greater detail.

Traditional physics instruction continues to be the most prevalent form of physics instruction in today's colleges and universities. This study provides evidence to indicate that one way to improve the experience and knowledge of college physics students is for instructors to be more effective in helping students develop an understanding of the nature of science, in particular their knowledge of models in science. In addition, to improve conceptual understanding of physics topics, instructors must pay careful attention to the models used by students in order to provide examples that both challenge students' naïve views and encourage the development of expert models.

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APPENDICES

APPENDIX A

SUMS Instrument

STUDENTS' UNDERSTANDING OF THE USE OF MODELS IN SCIENCE (SUMS)

INSTRUCTIONS: Please rate how strongly you agree or disagree with each of the following statements by placing a check mark in the appropriate box.

1. Many models may be used to express features of a science phenomenon by showing different perspectives to view an object.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
2. Many models represent different versions of the phenomenon.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
3. Models can show the relationship of ideas clearly.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
4. Many models are used to show how it depends on individual's different ideas on what things look like or how they work.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
5. Many models may be used to show different sides or shapes of an object.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
6. Many models show different parts of an object or show the objects differently.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
7. Many models show how different information is used.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
8. A model has what is needed to show or explain a scientific phenomenon.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
9. A model should be an exact replica.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
10. A model needs to be close to the real thing.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
11. A model needs to be close to the real thing by being very exact, so nobody can disprove it.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
12. Everything about a model should be able to tell what it represents.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
13. A model needs to be close to the real thing by being very exact in every way except for size.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
14. A model needs to be close to the real thing by giving the correct information and showing what the object/thing looks like.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
15. A model shows what the real thing does and what it looks like.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
16. Models show a smaller scale size of something.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
17. Models are used to physically or visually represent something.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
18. Models help create a picture in your mind of the scientific happening.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

19. Models are used to explain scientific phenomena.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
20. Models are used to show an idea.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
21. A model can be a diagram or a picture, a map, graph or a photo.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
22. Models are used to help formulate ideas and theories about scientific events.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
23. Models are used to show how they are used in scientific events.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
24. Models are used to make and test predictions about a scientific event.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
25. A model can change if new theories or evidence prove otherwise.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
26. A model can change if there are new findings.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
27. A model can change if there are changes in data or belief.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

APPENDIX B

CSEM Instrument

Conceptual Survey in Electricity and Magnetism (CSEM)

In any question referring to current, conventional current will be used (where conventional current is the flow of positive charges). In addition, all effects due to the earth's magnetic field will be so small that they will be ignored. Note that the term "particle" is meant to be an object without size or structure.

1. A hollow metal sphere is electrically neutral (no excess charge). A small amount of negative charge is suddenly placed at one point P on this metal sphere. If we check on this excess negative charge a few seconds later we will find one of the following possibilities:
   (a) All of the excess charge remains right around P.
   (b) The excess charge has distributed itself evenly over the outside surface of the sphere.
   (c) The excess charge is evenly distributed over the inside and outside surface.
   (d) Most of the charge is still at point P, but some will have spread over the sphere.
   (e) There will be no excess charge left.

2. A hollow sphere made out of electrically insulating material is electrically neutral (no excess charge). A small amount of negative charge is suddenly placed at one point P on the outside of this sphere. If we check on this excess negative charge a few seconds later we will find one of the following possibilities:
   (a) All of the excess charge remains right around P.
   (b) The excess charge has distributed itself evenly over the outside surface of the sphere.
   (c) The excess charge is evenly distributed over the inside and outside surface.
   (d) Most of the charge is still at point P, but some will have spread over the sphere.
   (e) There will be no excess charge left.

For questions 3 -5:
Two small objects each with a net charge of +Q exert a force of magnitude F on each other.

We replace one of the objects with another whose net charge is +4Q:

3. The original magnitude of the force on the +Q charge was F; what is the magnitude of the force on the +Q now?

   (a) 16F (b) 4F (c) F (d) F/4 (e) other

4. What is the magnitude of the force on the +4Q charge?

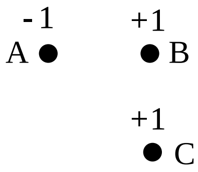
   (a) 16F (b) 4F (c) F (d) F/4 (e) other

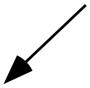
Next we move the +Q and +4Q charges to be 3 times as far apart as they were:

5. Now what is the magnitude of the force on the +4Q?

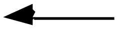
   (a) F/9 (b) F/3 (c) 4F/9 (d) 4F/3 (e) other

6. Which of the arrows is in the direction of the net force on charge B?



(a) 

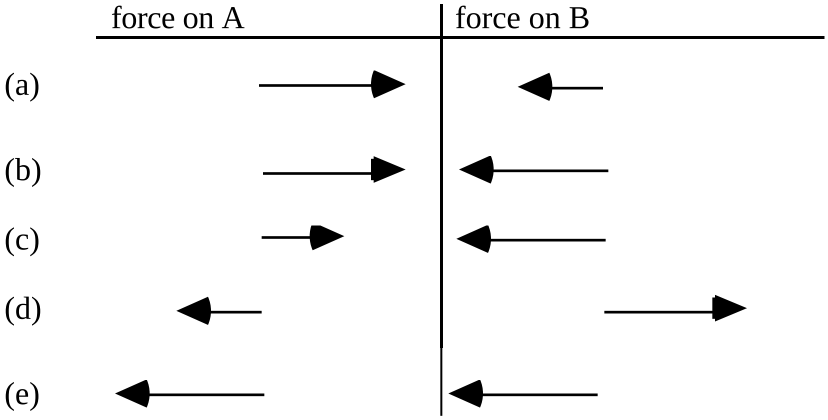
(b) 

(c) 

(d) 

(e) none of these

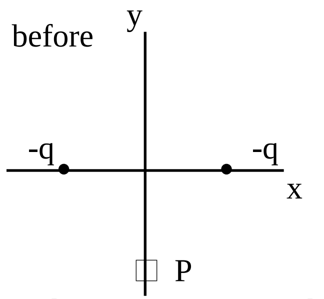
7. The picture below shows a particle (labeled B) which has a net electric charge of +1 unit. Several centimeters to the left is another particle (labeled A) which has a net charge of -2 units. Choose the pair of force vectors (the arrows) that correctly compare the electric force on A (caused by B) with the electric force on B (caused by A).

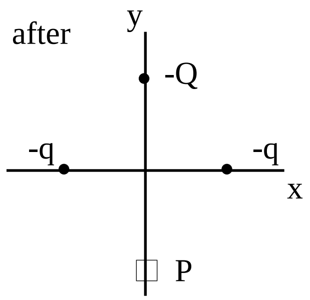


8. In the figure below, positive charges q_2 and q_3 exert on charge q_1 a net electric force that points along the +x axis. If a positive charge Q is added at (b,0), what now will happen to the force on q_1? (All charges are fixed at their locations.)

(a) No change in the size of the net force since Q is on the x-axis.
(b) The size of the net force will change but not the direction.
(c) The net force will decrease and the direction may change because of the interaction between Q and the positive charges q_2 and q_3.
(d) The net force will increase and the direction may change because of the interaction between Q and the positive charges q_2 and q_3.
(e) Cannot determine without knowing the magnitude of q_1 and/or Q.

9. In the figure below, the electric field at point P is directed upward along the y-axis. If a negative charge -Q is added at a point on the positive y-axis, what happens to the field at P? (All of the charges are fixed in position.)





(a) Nothing since -Q is on the y-axis.
(b) Strength will increase because -Q is negative.
(c) Strength will decrease and direction may change because of the interactions between -Q and the two negative q's.
(d) Strength will increase and direction may change because of the interactions between -Q and the two negative q's.
(e) Cannot determine without knowing the forces -Q exerts on the two negative q's.

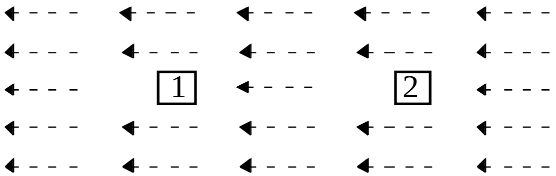
FOR QUESTIONS 10-11

A positive charge is placed at rest at the center of a region of space in which there is a uniform, three-dimensional electric field. (A uniform field is one whose strength and direction are the same at all points within the *region*.)

10. When the positive charge is released from rest in the uniform electric field, what will its subsequent motion be?
(a) It will move at a constant speed.
(b) It will move at a constant velocity.
(c) It will move at a constant acceleration.
(d) It will move with a linearly changing acceleration.
(e) It will remain at rest in its initial position.

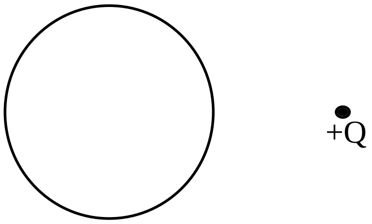
11. What happens to the electric potential energy of the positive charge, after the charge is released from rest in the uniform electric field?
(a) It will remain constant because the electric field is uniform.
(b) It will remain constant because the charge remains at rest.
(c) It will increase because the charge will move in the direction of the electric field.
(d) It will decrease because the charge will move in the opposite direction of the electric field.
(e) It will decrease because the charge will move in the direction of the electric field.

12. A positive charge might be placed at one of two different locations in a region where there is a uniform electric field, as shown below.



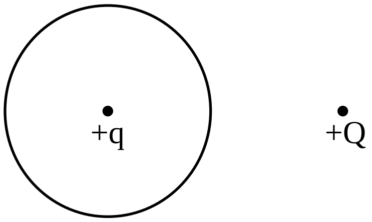
How do the electric forces on the charge at positions 1 and 2 compare?
(a) Force on the charge is greater at 1.
(b) Force on the charge is greater at 2.
(c) Force at both positions is zero.
(d) Force at both positions is the same but not zero.
(e) Force at both positions has the same magnitude but is in opposite directions.

13. The figure below shows a hollow conducting metal sphere which was given initially an evenly distributed positive (+) charge on its surface. Then a positive charge +Q was brought up near the sphere as shown. What is the direction of the electric field at the center of the sphere after the positive charge +Q is brought up near the sphere?



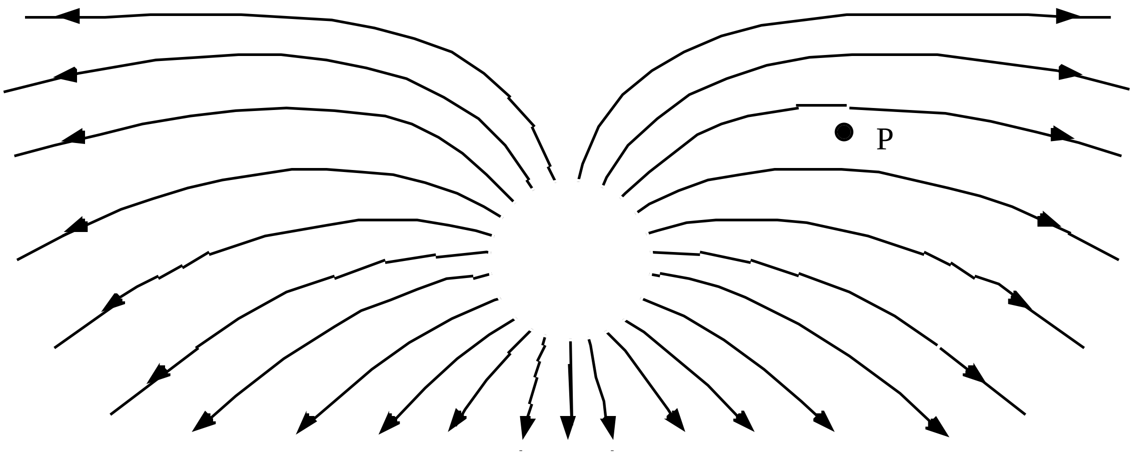
(a) Left
(b) Right
(c) Up
(d) Down
(e) Zero field

14. The figure below shows an electric charge q located at the center of a hollow uncharged conducting metal sphere. Outside the sphere is a second charge Q. Both charges are positive. Choose the description below that describes the net electrical forces on each charge in this situation.

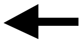
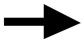


(a) Both charges experience the same net force directed away from each other.
(b) No net force is experienced by either charge.
(c) There is no force on Q but a net force on q.
(d) There is no force on q but a net force on Q.
(e) Both charges experience a net force but they are different from each other.

USE THE FOLLOWING ELECTRIC FIELD DIAGRAM FOR QUESTION 15.



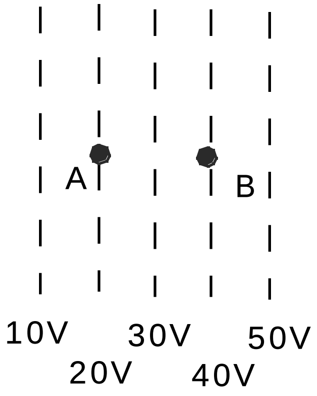
15. What is the direction of the electric force on a negative charge at point P in the diagram above?

(a) 
(b) 
(c) 
(d) 
(e) the force is zero

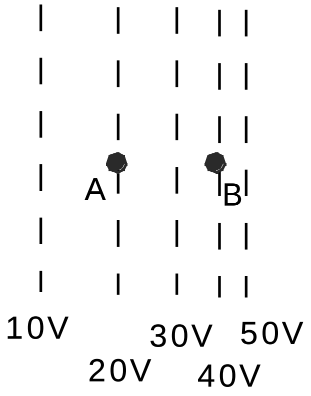
16. An electron is placed at a position on the x-axis where the electric potential is + 10 V. Which idea below best describes the future motion of the electron?
(a) The electron will move left (-x) since it is negatively charged.
(b) The electron will move right (+x) since it is negatively charged.
(c) The electron will move left (-x) since the potential is positive.
(d) The electron will move right (+x) since the potential is positive.
(e) The motion cannot be predicted with the information given.

FOR QUESTIONS 17-19

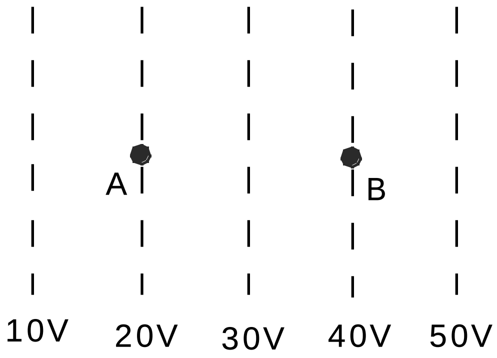
In the figures below, the dotted lines show the equipotential lines of electric fields. (A charge moving along a line of equal potential would have a constant electric potential energy.) A charged object is moved directly from point A to point B. The charge on the object is +1 μC.



I



II



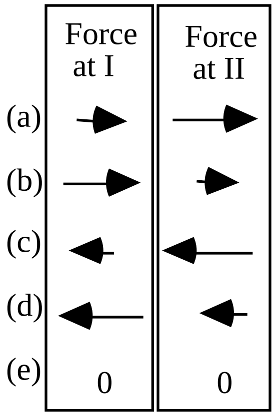
III

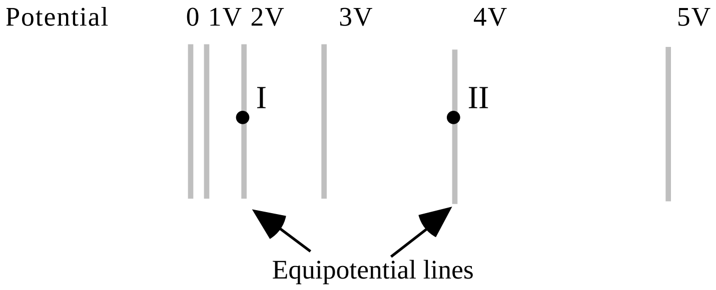
17. How does the amount of work needed to move this charge compare for these three cases?
(a) Most work required in I.
(b) Most work required in II.
(c) Most work required in III.
(d) I and II require the same amount of work but less than III.
(e) All three would require the same amount of work.

18. How does the magnitude of the electric field at B compare for these three cases?
(a) I > III > II
(b) I > II > III
(c) III > I > II
(d) II > I > III
(e) I = II = III

19. For case III what is the direction of the electric force exerted by the field on the + 1 μC charged object when at A and when at B?
(a) left at A and left at B
(b) right at A and right at B
(c) left at A and right at B
(d) right at A and left at B
(e) no electric force at either.

20. A positively-charged proton is first placed at rest at position I and then later at position II in a region whose electric potential (voltage) is described by the equipotential lines. Which set of arrows on the left below best describes the relative magnitudes and directions of the electric force exerted on the proton when at position I or II?



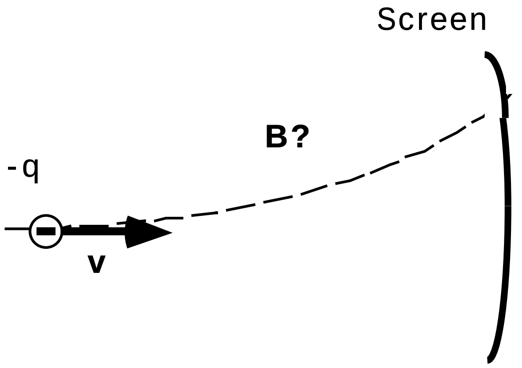


21. What happens to a positive charge that is placed at rest in a uniform magnetic field? (A uniform field is one whose strength and direction are the same at all points.)

(a) It moves with a constant velocity since the force has a constant magnitude.
(b) It moves with a constant acceleration since the force has a constant magnitude.
(c) It moves in a circle at a constant speed since the force is always perpendicular to the velocity.
(d) It accelerates in a circle since the force is always perpendicular to the velocity.
(e) It remains at rest since the force and the initial velocity are zero.

22. An electron moves horizontally toward a screen. The electron moves along the path that is shown because of a magnetic force caused by a magnetic field. In what direction does that magnetic field point?

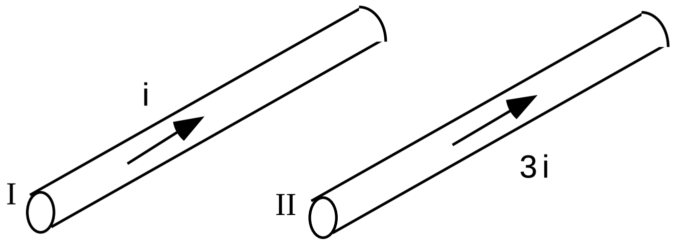
(a) Toward the top of the page
(b) Toward the bottom of the page
(c) Into the page
(d) Out of the page
(e) The magnetic field is in the direction of the curved path.



23. Wire 1 has a large current i flowing out of the page (⊙), as shown in the diagram. Wire 2 has a large current i flowing into the page (⊗). In what direction does the magnetic field point at position P?

(a) ↑ (b) ← (c) → (d) ↓ (e) none of the above.

24. Two parallel wires I and II that are near each other carry currents i and 3i both in the same direction. Compare the forces that the two wires exert on each other.



(a) Wire I exerts a stronger force on wire II than II exerts on I.
(b) Wire II exerts a stronger force on wire I than I exerts on II.
(c) The wires exert equal magnitude attractive forces on each other.
(d) The wires exert equal magnitude repulsive forces on each other.
(e) The wires exert no forces on each other.

25. The figures below represent positively charged particles moving in the same uniform magnetic field. The field is directed from left to right. All of the particles have the same charge and the same speed v. Rank these situations according to the magnitudes of the force exerted by the field on the moving charge, from greatest to least.

(a) I = II = III

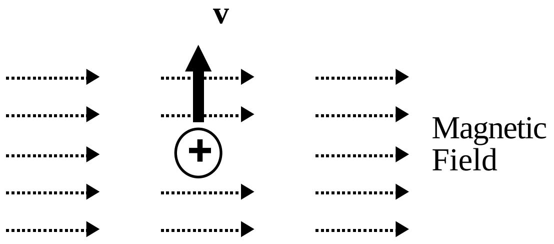
(b) III > I > II

(c) II > I > III

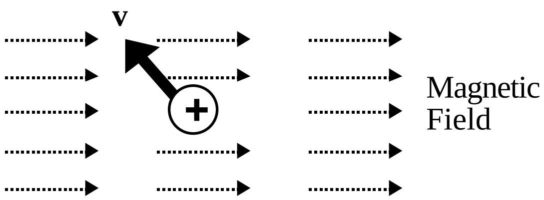
(d) I > II > III

(e) III > II > I

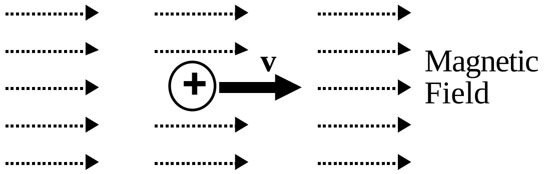
I



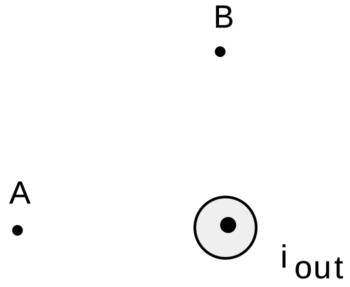
II



III

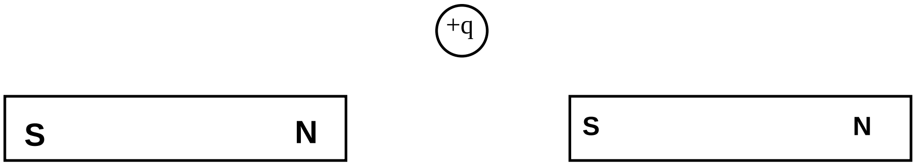


26. The diagram shows a wire with a large electric current i (⊙) coming out of the paper. In what direction would the magnetic field be at positions A and B?



	A	B
(a)	↓	←
(b)	→	↓
(c)	↑	→
(d)	←	↑
(e)	None of these	

27. A positively-charged particle (+q) is at rest in the plane between two fixed bar magnets, as shown. The magnet on the left is three times as strong as the magnet on the right. Which choice below best represents the resultant **MAGNETIC** force exerted by the magnets on the charge?



(a) → (b) ↙ (c) ← (d) ↘ (e) Zero

28. Two identical loops of wire carry identical currents i. The loops are located as shown in the diagram. Which arrow best represents the direction of the magnetic field at the point P midway between the loops?

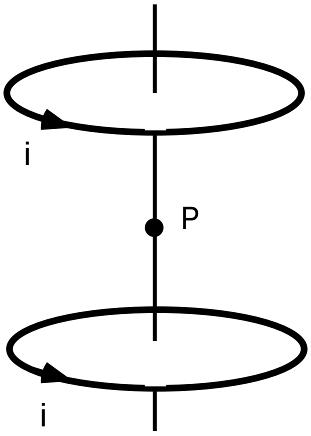
(a) ↓

(b) →

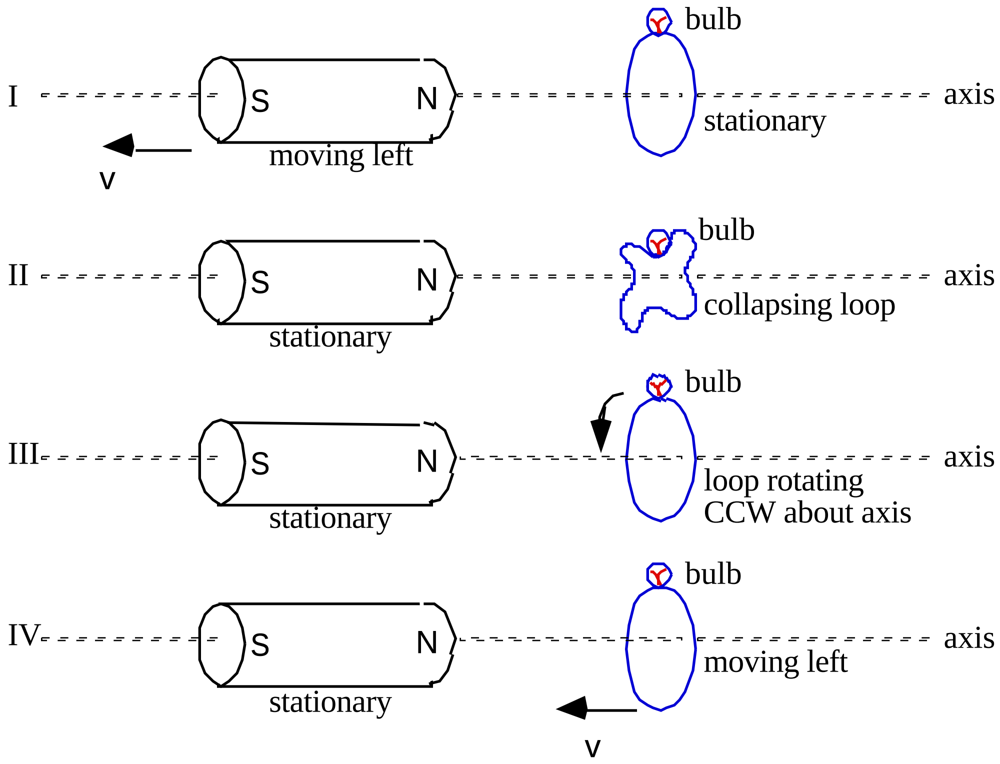
(c) ↑

(d) ←

(e) Zero



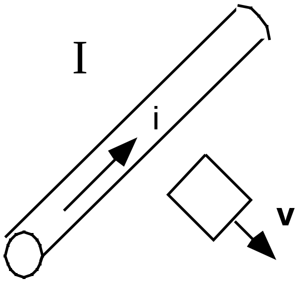
The five separate figures below involve a cylindrical magnet and a tiny light bulb connected to the ends of a loop of copper wire. These figures are to be used in the following question. The plane of the wire loop is perpendicular to the reference axis. The states of motion of the magnet and of the loop of wire are indicated in the diagram. Speed will be represented by v and CCW represents counter clockwise.

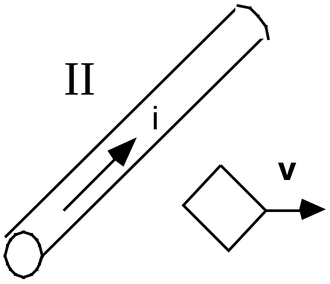


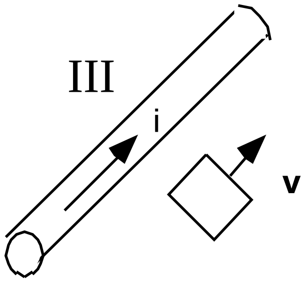
29. In which of the above figures will the light bulb be glowing?

(a) I, III, IV (b) I, IV (c) I, II, IV (d) IV (e) None of these

30. A very long straight wire carries a large steady current i. Rectangular metal loops, in the same plane as the wire, move with velocity **v** in the directions shown. Which loop will have an induced current?







(a) only I and II

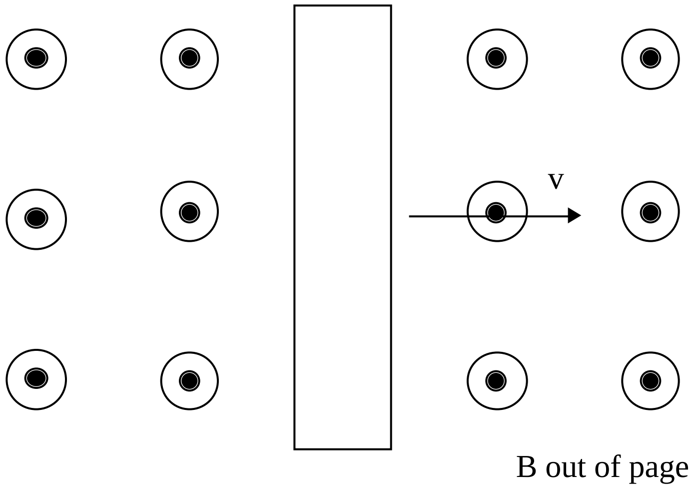
(b) only I and III

(c) only II and III

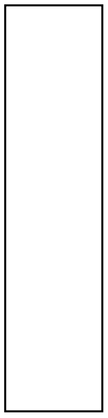
(d) all of the above.

(e) none of the above.

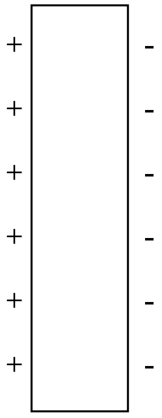
31. A neutral metal bar is moving at constant velocity v to the right through a region where there is a uniform magnetic field pointing out of the page. The magnetic field is produced by some large coils which are not shown on the diagram.



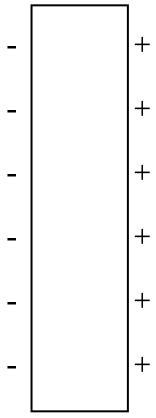
Which one of the following diagrams best describes the charge distribution on the surface of the metal bar?



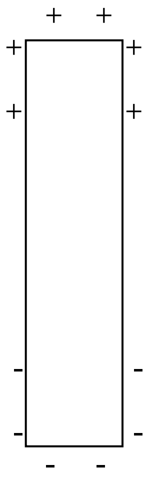
(a)



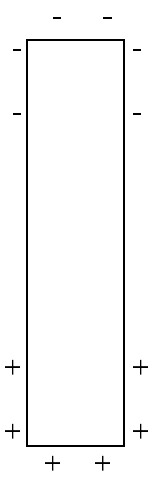
(b)



(c)

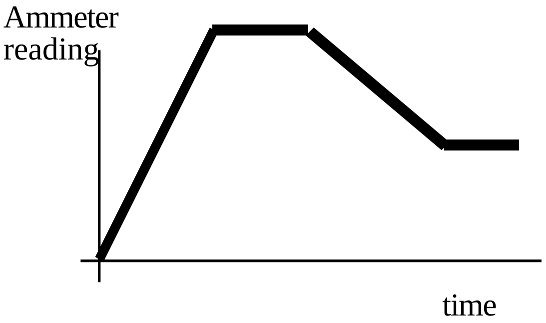


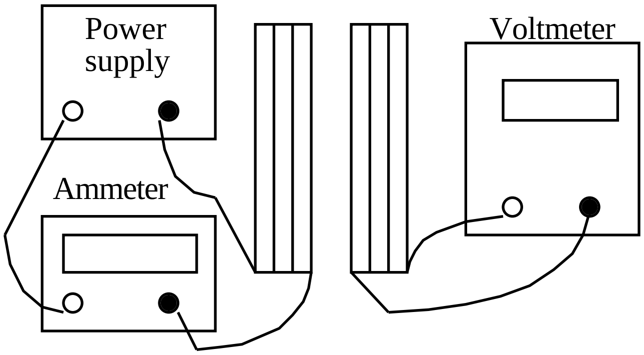
(d)



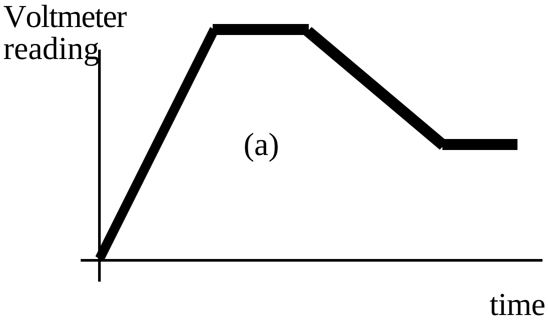
(e)

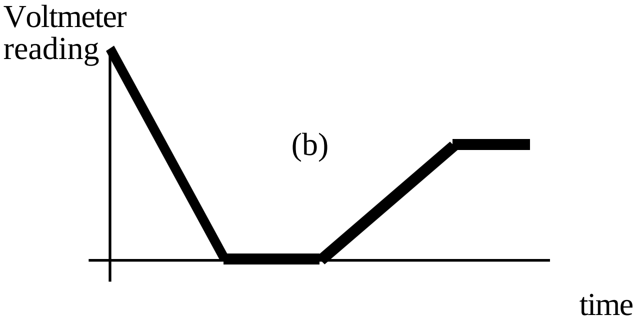
32.A variable power supply is connected to a coil and an ammeter, and the time dependence of the ammet reading is shown. A nearby coil is connected to a voltmeter.

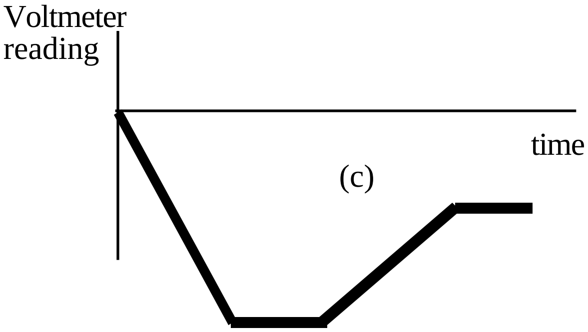


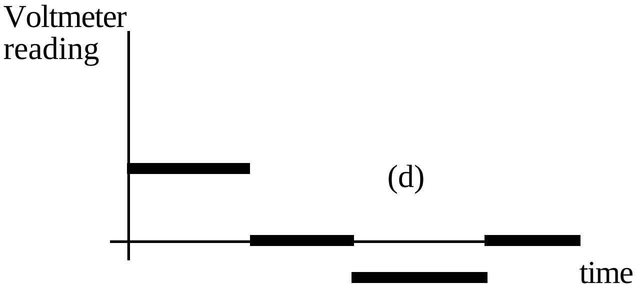


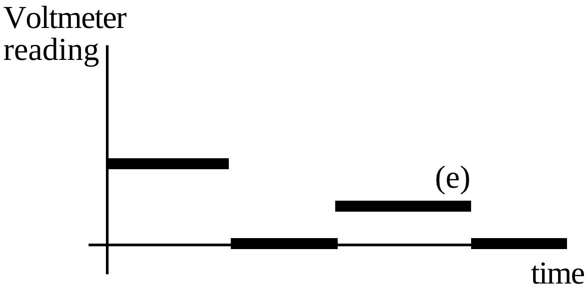
Which of the following graphs correctly shows the time dependence of the voltmeter reading?











APPENDIX C

Model Plots

Model Plots

Table 23 – Model Points

	Overall		Calculus-Based (CB)		Algebra-Based (AB)	
	Pre	Post	Pre	Post	Pre	Post
Topic 2	(0.33, 0.11)	(0.38, 0.07)	(0.36, 0.10)	(0.38, 0.03)	(0.31, 0.13)	(0.36, 0.14)
Topic 3	(0.23, 0.09)	(0.46, 0.05)	(0.30, 0.04)	(0.57, 0.03)	(0.15, 0.17)	(0.32, 0.09)
Topic 4	(0.20, 0.28)	(0.25, 0.21)	(0.20, 0.27)	(0.26, 0.20)	(0.20, 0.29)	(0.25, 0.23)
Topic 5	(0.22, 0.30)	(0.27, 0.28)	(0.24, 0.28)	(0.29, 0.26)	(0.19, 0.33)	(0.25, 0.29)
Topic 8	(0.03, 0.63)	(0.24, 0.39)	(0.04, 0.61)	(0.29, 0.35)	(0.02, 0.66)	(0.16, 0.46)
Topic 9	(0.01, 0.60)	(0.29, 0.25)	(0.03, 0.57)	(0.31, 0.23)	(0.01, 0.65)	(0.23, 0.31)
Topic 11	(0.09, 0.48)	(0.07, 0.46)	(0.09, 0.48)	(0.06, 0.43)	(0.09, 0.48)	(0.09, 0.50)

Figures 13 and 14 – Topic 2 (*Coulomb's Law*)
Student Performance in CB and AB Course Model Plot

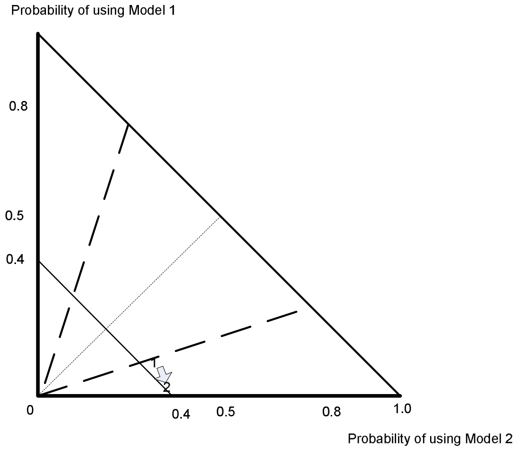


Figure 13 – CB Course

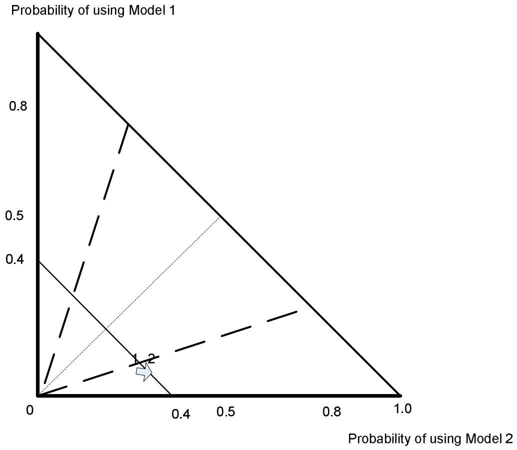


Figure 14 – AB Course

Figures 15 and 16 – Topic 3 (*Electric Force and Field Superposition*)
Student Performance in CB and AB Course Model Plot

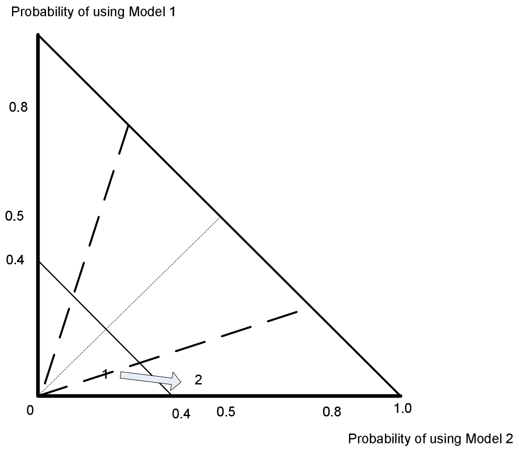


Figure 15 – CB Course

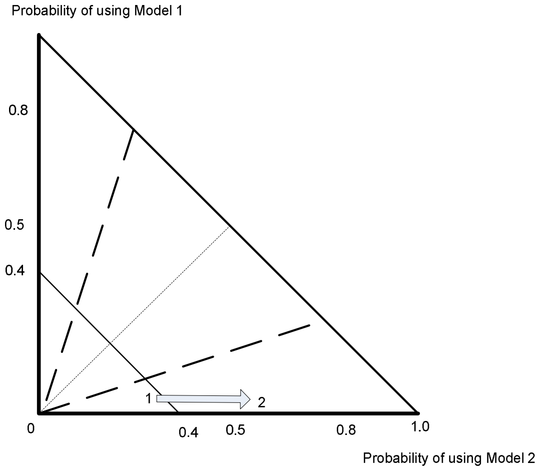


Figure 16 – AB Course

Figures 17 and 18 – Topic 4 (*Force Caused by an Electric Field*)
Student Performance in CB and AB Course Model Plot

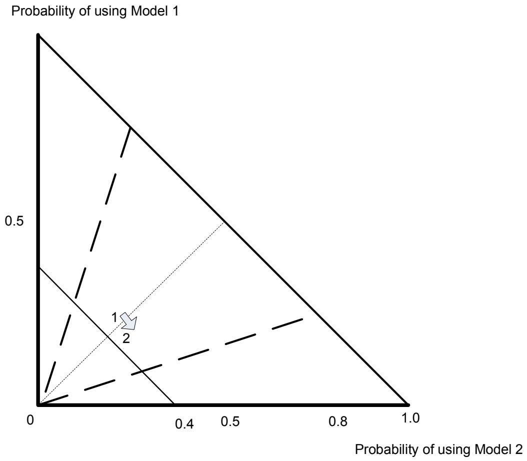


Figure 17 – CB Course

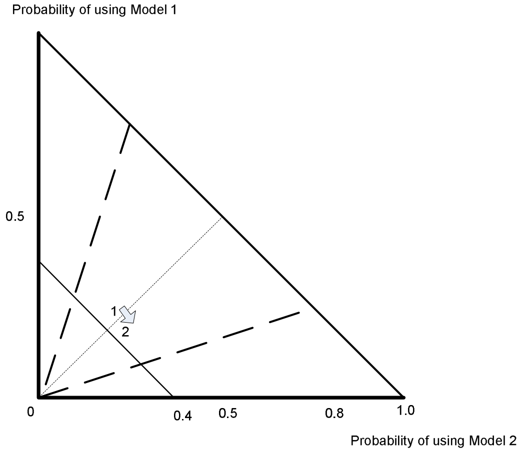


Figure 18 – AB Course

Figures 19 and 20 – Topic 5 (*Work, Electric Potential, Field & Force*)
Student Performance in CB and AB Course Model Plot

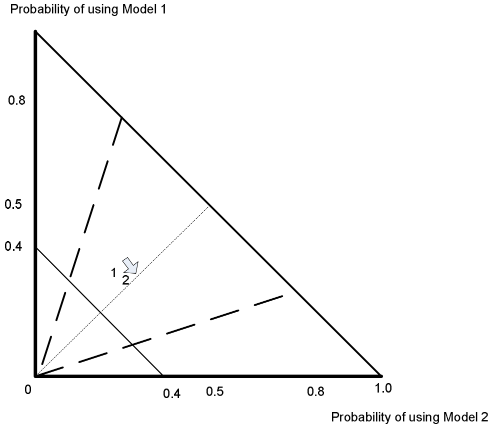


Figure 19 – CB Course

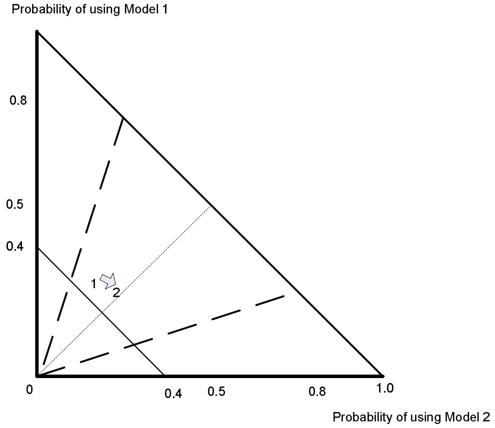


Figure 20 – AB Course

Figures 21 and 22 – Topic 8 (*Magnetic Field Caused by a Current*)
Student Performance in CB and AB Course Model Plot

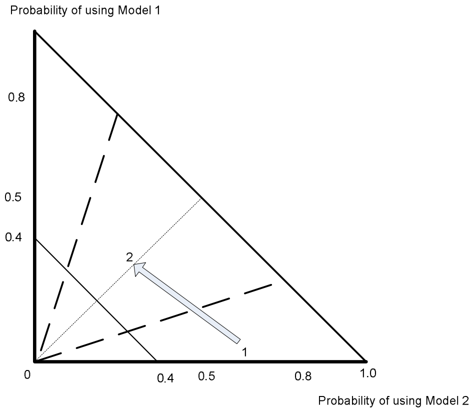


Figure 21 – CB Course

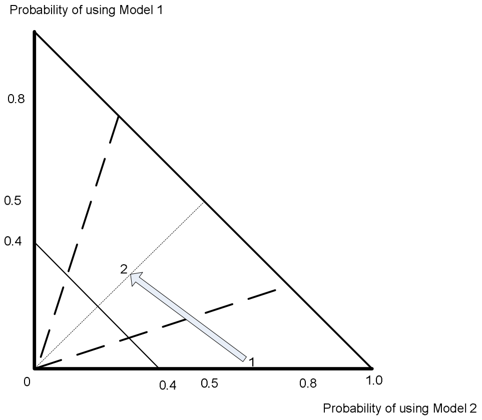


Figure 22 – AB Course

Figures 23 and 24 – Topic 9 (*Magnetic Field Superposition*) Student Performance in CB and AB Course Model Plot

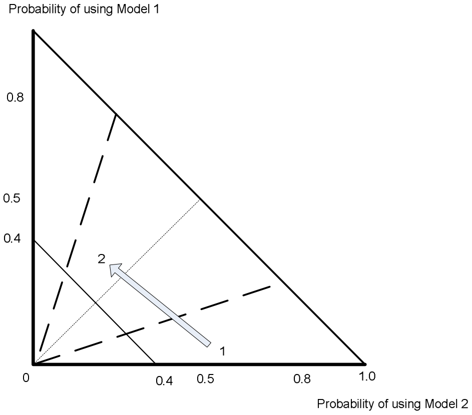


Figure 23 – CB Course

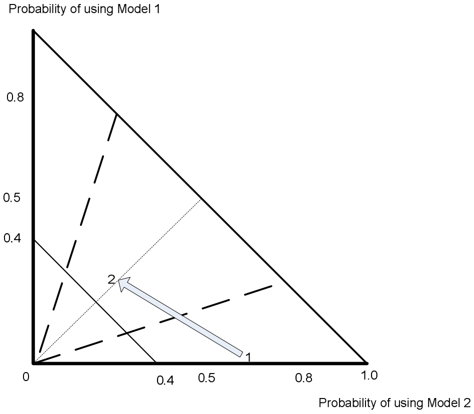


Figure 24 – AB Course

APPENDIX D

IRB Approval Letter

University Committee for the Protection
of Human Subjects in Research
University of New Orleans

Campus Correspondence

Principal Investigator: Andy Talmadge

Co-Investigator: Kristy Philippi

Date: May 2, 2008

Protocol Title: "College students' views of the use of models in sciences and their effects on conceptual understanding of electricity and magnetism: a comparison of modeling and traditional instruction"

IRB#: 03May08

The IRB has deemed that the research and procedures described in this protocol application are exempt from federal regulations under 45 CFR 46.101 categories 1. This minimal-risk study will be conducted in established or commonly accepted educational settings, involving normal educational practices.

Exempt protocols do not have an expiration date; however, if there are any changes made to this protocol that may cause it to be no longer exempt from CFR 46, the IRB requires another standard application from the investigator(s) which should provide the same information that is in this application with changes that may have changed the exempt status.

If an adverse, unforeseen event occurs (e.g., physical, social, or emotional harm), you are required to inform the IRB as soon as possible after the event.

Best wishes on your project.
Sincerely,

Robert D. Laird, Ph.D., Chair
Committee for the Protection of Human Subjects in Research

VITA

Kristen Haber Philippi earned a BS and a MA from the University of New Orleans and a MS from Loyola University in New Orleans. She has taught mathematics and physics in the Jefferson Parish Public School System and developmental mathematics at the University of New Orleans. She was the Jefferson Parish Public School System supervisor for K-12 mathematics education and was most recently, the founding principal of Patrick F. Taylor Science & Technology Academy, a Jefferson Parish Public School for students in grades six through twelve.

Under her guidance, Taylor has the distinction of being the first public school in the state where each student is issued and uses a laptop in a business-like environment. She is affiliated with the New Technology Network of Schools, a national reform movement to provide a 21st Century education to today's high school students. Through her work with the New Tech Network and as principal of Taylor Academy, she has been recognized as a leader in using technology in education on the regional (Jefferson Parish Economic Development Commission Educator of the Year, Northshore Excellence in Teaching with Technology Administrator of the Year, Gambit Weekly's 40 Under 40), state (Louisiana Computer Using Educators Administrator of the Year) and national level (Cable's Leaders in Learning).