HOW DO PRE-SERVICE TEACHERS PICTURE VARIOUS ELECTROMAGNETIC PHENOMENON? A QUALITATIVE STUDY OF PRE-SERVICE TEACHERS’ CONCEPTUAL UNDERSTANDING OF FUNDAMENTAL ELECTROMAGNETIC INTERACTION.

A DISSERTATION

SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE

DOCTOR OF EDUCATION

BY

CHRISTOPHER P. BEER

APPROVED BY:

Joel Bryan, Chairperson  Date

_________________________________________  __________________

Eric Hedin  Date

_________________________________________  __________________

Carolyn Kapinus  Date

_________________________________________  __________________

Gregory Marchant  Date

_________________________________________  __________________

Robert Morris, Dean of Graduate School  Date

BALL STATE UNIVERSITY

MUNCIE, INDIANA

DECEMBER 2010
HOW DO PRE-SERVICE TEACHERS PICTURE VARIOUS ELECTROMAGNETIC PHENOMENON? A QUALITATIVE STUDY OF PRE-SERVICE TEACHERS’ CONCEPTUAL UNDERSTANDING OF FUNDAMENTAL ELECTROMAGNETIC INTERACTION.

A DISSERTATION
SUBMITTED TO THE GRADUATE SCHOOL
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE
DOCTOR OF EDUCATION
BY
CHRISTOPHER P. BEER
DISSERTATION ADVISOR: DR. JOEL A. BRYAN

BALL STATE UNIVERSITY
MUNCIE, INDIANA
DECEMBER 2010
ACKNOWLEDGEMENTS

This dissertation would not have been possible without the continual support of many people. First and foremost I would like to thank my dissertation advisor Dr. Joel Bryan. Dr. Bryan was instrumental in helping me convert my assortment of potential research ideas into a concise, interesting research topic. Dr. Bryan was always available with helpful information and ideas when I became bogged down during the completion of this project. Lastly I would like to thank Dr. Bryan for never becoming frustrated during the long course of completing this project and the many obstacles that appeared along the way. If I ever advise a student during a dissertation I will strive to be as good an advisor.

I would also like to thank the rest of my committee. Their advice, especially during the proposal segment of my project, helped me stay focused on the primary objective of the project and not become sidetracked on tangential subjects. During communication the committee members were always encouraging and helped me to keep working until the project was finally finished. Dr. Marchant was especially helpful with formatting and organizational issues.

Without the support of my immediate family this project would have never come to fruition. I would like to thank my parents for always believing in my ability to complete this dissertation and giving me the impetus to pursue my education as far as I could. My wife Sheri has been a constant source of encouragement during the past four years. She never hesitated to help me in completing this project, whether it be sorting papers or proofreading a chapter.
ABSTRACT

DISSERTATION TITLE: How do pre-service teachers picture various electromagnetic phenomenon? A qualitative study of pre-service teachers' conceptual understanding of fundamental electromagnetic interaction.

STUDENT: Christopher P. Beer

DEGREE: Doctor of Education

COLLEGE: College of Sciences and Humanities

DATE: December, 2010

PAGES: 398

This study analyzes the nature of pre-service teachers’ conceptual models of various electromagnetic phenomena, specifically electrical current, electrical resistance, and light/matter interactions. This is achieved through the students answering the three questions on electromagnetism using a free response approach including both verbal and pictorial representation. The student responses are then analyzed qualitatively and quantitatively utilizing a multi-tiered approach. These analyses include epistemological representation, misconceptions, correct conceptions, and the impact of high school physics exposure on student conceptions. This study is unique in three primary respects; the free response
questionnaire approach, a subject group that consists of pre-service teachers, and a primarily female demographic.
# TABLE OF CONTENTS

**LIST OF TABLES** .............................................................................................................. ix

**LIST OF FIGURES** .......................................................................................................... xi

**Chapter 1: Introduction** ..................................................................................................... 1
   - History of Scientific Literacy .................................................................................. 3
   - Importance of Scientific Literacy ......................................................................... 8
   - Statement of the Issue .......................................................................................... 16
   - Purpose of the Study ............................................................................................ 20
   - Significance of the Research .............................................................................. 20
   - Introduction Summary ......................................................................................... 22

**Chapter 2: Review of Literature** ....................................................................................... 25
   - Physics Education Today .................................................................................... 26
   - Knowledge of the Scientific Process .................................................................. 29
   - Student Learning in Physics .............................................................................. 42
   - Student Physics Conceptions ............................................................................. 44
      - Origin of student conceptions ....................................................................... 45
      - Students conceptions of mechanics ............................................................. 53
      - Students conceptions of light ...................................................................... 59
      - Students conceptions of electricity .............................................................. 64
   - Theories of Conceptual Evolution ...................................................................... 73
      - Expert/novice approach ............................................................................... 78
      - Constructivist approach .............................................................................. 83
   - Gender Differences in Conceptions .................................................................... 92
   - Pre-service Elementary Teachers ...................................................................... 96
   - Success in College Physics ................................................................................. 97
LIST OF TABLES

Table 2.1. Epistemological Representations.................................37
Table 3.1. Light Properties of Material Objects........................132
Table 3.2. Types of Magnetism..................................................145
Table 4.1. Epistemological Representation
Frequencies Including Percent of Students with Phenomenon-based reasoning........180
Table 4.2. Epistemological Representation
With Number of Phenomenon-based Responses Compared to Course Grade...............184
Table 4.3. Comparison of Students With and Without Light Misconceptions on Final Course Grade......................................................203
Table 4.4. Comparison of Students With and Without Current Misconceptions on Final Course Grade......................................................229
Table 4.5. Comparison of Students With and Without Resistor Misconceptions on Final Course Grade......................................................244
Table 4.6. Frequencies of Student Conceptions for the Various Questionnaires.....................287
Table 4.7. Total Number of Concepts Demonstrated for Each Questionnaire......................................................291
Table 4.8. Correctness Categorization Criteria.............................294
Table 4.9. Correctness Frequencies for the Three Different Questions......................................................313
Table 4.10. Effect of High School Physics on Final Grade......................................................316
Table 4.11. Associations Between High School Physics and Student Misconceptions..........................318
Table 4.12. Associations Between High School Physics and Epistemological Representation......................320
Table 4.13. Associations Between High School Physics and Concepts Demonstrated..................................321
Table 4.14. Associations Between High School Physics and Correctness.............................................322
Table 4.15. Summary of Differences Due to High School Physics Exposure for Light Question.......................323
Table 4.16. Summary of Differences Due to High School Physics Exposure for Current Question..................324
Table 4.17. Summary of Differences Due to High School Physics Exposure.............................................325
Table 4.18. Number of Misconceptions per Questionnaire Version.........................................................329
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Number of physics doctorates awarded 1966 - 2006</td>
<td>2</td>
</tr>
<tr>
<td>1.2</td>
<td>Worldwide literacy rate</td>
<td>5</td>
</tr>
<tr>
<td>3.1</td>
<td>Number of students responding to each question</td>
<td>123</td>
</tr>
<tr>
<td>3.2</td>
<td>Three different versions of glass representations</td>
<td>126</td>
</tr>
<tr>
<td>3.3</td>
<td>Typical diagram of the law of reflection</td>
<td>128</td>
</tr>
<tr>
<td>3.4</td>
<td>Typical classroom representation of Snell’s Law of refraction</td>
<td>130</td>
</tr>
<tr>
<td>3.5</td>
<td>Typical slide depicting the wavelength nature of color</td>
<td>133</td>
</tr>
<tr>
<td>3.6</td>
<td>Typical slide from class lecture</td>
<td>139</td>
</tr>
<tr>
<td>3.7</td>
<td>Typical example of electric field lines</td>
<td>141</td>
</tr>
<tr>
<td>4.1</td>
<td>Logical inconsistency in the light question</td>
<td>156</td>
</tr>
<tr>
<td>4.2</td>
<td>Example of phenomenon-based representation</td>
<td>158</td>
</tr>
<tr>
<td>4.3</td>
<td>Example of phenomenon-based representation</td>
<td>160</td>
</tr>
<tr>
<td>4.4</td>
<td>Example of relation-based representation</td>
<td>162</td>
</tr>
<tr>
<td>4.5</td>
<td>Example of phenomenon-based representation</td>
<td>164</td>
</tr>
<tr>
<td>4.6</td>
<td>Example of phenomenon-based representation</td>
<td>166</td>
</tr>
</tbody>
</table>
Figure 4.7. Example of relation-based representation.................................................................168

Figure 4.8. Example of relation-based representation.................................................................170

Figure 4.9. Example of phenomenon-based representation...........................................................172

Figure 4.10. Example of phenomenon-based representation...........................................................174

Figure 4.11. Example of relation-based representation.................................................................177

Figure 4.12. Example of relation-based representation.................................................................179

Figure 4.13. Example of nature of color misconception.................................................................186

Figure 4.14. Example of nature of color misconception.................................................................187

Figure 4.15. Example of nature of color misconception.................................................................189

Figure 4.16. Example of nature of color misconception.................................................................190

Figure 4.17. Example of perception of color misconception...........................................................192

Figure 4.18. Example of perception of color misconception...........................................................193

Figure 4.19. Example of perception of color misconception...........................................................194

Figure 4.20. Example of color absorption misconception.............................................................196

Figure 4.21. Example of color absorption misconception.............................................................198
Figure 4.22. Example of color absorption misconception………………………………………………………………………………200
Figure 4.23. Example of color absorption misconception………………………………………………………………………………202
Figure 4.24. General Form of clashing current misconception………………………………………………………………………………205
Figure 4.25. Example of clashing current misconception………………………………………………………………………………207
Figure 4.26. Example of clashing current misconception………………………………………………………………………………209
Figure 4.27. Example of wave current misconception………………………………………………………………………………………211
Figure 4.28. Example of wave current misconception………………………………………………………………………………………213
Figure 4.29. Example of current flow misconception………………………………………………………………………………………216
Figure 4.30. Example of current flow misconception………………………………………………………………………………………218
Figure 4.31. Example of charge wire misconception………………………………………………………………………………………221
Figure 4.32. Example of charge wire misconception………………………………………………………………………………………223
Figure 4.33. Example of moving positive charge misconception……………………………………………………………………………226
Figure 4.34. Example of Moving Positive Charge misconception……………………………………………………………………………228
Figure 4.35. Example of variable speed misconception………………………………………………………………………………………231
Figure 4.36. Example of variable speed misconception………………………………………………………………………………………234
Figure 4.37. Example of variable current density misconception
Figure 4.38. Example of variable current density misconception
Figure 4.39. Example of external charge misconception
Figure 4.40. Example of external charge misconception
Figure 4.41. Example of light rays as straight lines
Figure 4.42. Example of curved light rays
Figure 4.43. Example of uniquely depicted light rays
Figure 4.44. Example of the concept of reflection demonstrated
Figure 4.45. Example of an incorrect depiction of reflection
Figure 4.46. Example of the law of refraction
Figure 4.47. Example of an incorrect depiction of refraction
Figure 4.48. Example of the concept of seeing
Figure 4.49. Example of an incorrect depiction of seeing
Figure 4.50. Example of the discreet charge conception
Figure 4.51. Example of continuous charge distribution
Figure 4.52. Example of the equal charges conception

Figure 4.53. Example of non-equal charge distribution

Figure 4.54. Example of moving negative charge conception

Figure 4.55. Example of indeterminate moving charge

Figure 4.56. Example of negative discreet charge carrier conception

Figure 4.57. Example of negative discreet charge carrier conception

Figure 4.58. Example of current/resistance proportional concept

Figure 4.59. Example of current/resistance proportional concept

Figure 4.60. Example of “0” level work

Figure 4.61. Example of “1” level work

Figure 4.62. Example of “2” level work

Figure 4.63. Example of “0” level work

Figure 4.64. Example of “1” level work

Figure 4.65. Example of “2” level work

Figure 4.66. Example of “0” level work

Figure 4.67. Example of “1” level work

Figure 4.68. Example of “2” level work

Figure 4.69. Typical example of coding problem
Chapter 1: Introduction

“The illiterate of the 21st century will not be those who cannot read and write, but those who cannot learn, unlearn, and relearn”

- Alvin Toffler, Rethinking the Future (1998)

The importance of comprehending nature is recognized by people all across the world, this basic need to understand is independent of social or cultural background. Our understanding of the world has improved dramatically in the past few centuries and continues to enlarge at an ever increasing rate, with commentators creating the term “information explosion” to classify the current era. With the advent of the internet the ability for people to create and transmit information has reached proportions hitherto unforeseen.

While there is no debate that humankind is greatly increasing its knowledge and technical ability, the consensus is not nearly so great if we choose to look at how well individuals are learning in this new environment. It seems as if the human race is increasing its knowledge base much faster than individuals are. More specifically, the scientific literacy of the individual does not seem to
be keeping up with the rapid increase in scientific knowledge. Physics is rightly considered the fundamental natural science and thus can serve as a bellwether in regards to science education. As can be seen in Figure 1.1 the number of students in the United States receiving a doctoral degree in physics reached a peak in 1971 and has not again reached that level even though the current U.S. population is approximately 100 million more people than in 1971 (US Census Bureau, 2009).

Figure 1.1. Number of physics doctorates awarded 1966 – 2006.

Note: Data from National Science Foundation (NSF) website (www.nsf.gov).

While the data on physics doctorates shows a significant decline as a percentage of population, the data is not all
bad. The total number of scientists has increased over the past 20 years, even though they still only comprise approximately 1% of the total U.S. workforce (Redish, 2002). While the number of physics doctorates is decreasing as a percentage of population, what is more troubling is the physics literacy of the average citizen.

**History of Scientific Literacy**

If there has been one overriding change for mankind in the last century it has been the explosion of science and technology. Virtually all aspects of our daily lives are touched by some form of technology that our ancestors could scarcely have dreamed of. Not only does science affect us through the application of technology, it presents us with ethical and political dilemmas previously unseen in human history. In order for the human race to survive and prosper, we will need to be able to meet the challenges our increasing knowledge presents to us. The list of science related issues threatening humankind includes not only global climate change, environmental degradation, nuclear war, population growth, bioengineering, genetically modified food crops, and electronic privacy intrusions but also future problems we cannot possibly foresee.
In order to ensure that we will be able to meet these challenges successfully, future generations will need to have extensive scientific training.

We have already seen the beginnings of this. In response to the growing technical nature of society, governments in developed countries have generally increased the duration of education required of its citizenry over the past century. In ancient times the average person was illiterate and never had the luxury of attending a formal school. As human civilization progressed compulsory education was instituted for children up until their early teen years. Later this was extended to their late teens. Today many students continue their education through their early twenties and beyond. The change from an uneducated, illiterate population to almost universal literacy was revolutionary and very productive in terms of human advancement. Figure 1.2 demonstrates that the literacy rate continues to increase, primarily due to increased literacy in underdeveloped countries.
This drastic change was required for people to function in a modern, primarily capitalistic world. The importance of education in modern society is codified in the 1948 Universal Declaration of Human Rights, Article 26 which reads:

(1) Everyone has the right to education. Education shall be free, at least in the elementary and fundamental stages. Elementary education shall be compulsory. Technical and professional education shall be made generally available and higher education shall be equally accessible to all on the basis of merit.

(2) Education shall be directed to the full development of the human personality and to the strengthening of respect for human rights and fundamental freedoms. It shall promote understanding, tolerance and friendship among all nations, racial or
religious groups, and shall further the activities of the United Nations for the maintenance of peace.
(3) Parents have a prior right to choose the kind of education that shall be given to their children.

Today the educational paradigm needs to be changed yet again. The changes now required have to do with scientific literacy, and how to ensure that everyone attains a certain level of proficiency. The previously held educational notion, especially in the United States, has generally been that only a small elite portion of society needed scientific training for their occupations as scientists and engineers, while the masses needed only the briefest introduction to scientific ideas (Bowles & Gintis, 2002). The results of this approach to education can be seen quite clearly in daily discourse. American citizens are uninformed on many issues of a scientific nature. Even the notion of what constitutes a scientific theory is misunderstood by a large portion of the American population. Many confuse scientific theories with educated guesses or tentative explanations, instead of rigorously tested explanations that have survived countless experiments designed to disprove them. Understanding how scientific theories are created and tested is fundamental to understanding the entire nature of science, which was
emphasized by Dagher and Brickhouse (2004) in the *International Journal of Science Education*, when they stated, “A clear understanding of the nature of scientific theories, how they are developed and validated, and what distinguishes them from laws and other non-scientific explanations is necessary for a comprehensive understanding of science” (p. 735).

For instance, when it comes to genetically modified (GM) foods, the American public is woefully informed. Only 19% of Americans surveyed could remember any news events or stories related to GM food. Even though approximately 60% to 70% of processed foods in the U.S. contain GM ingredients, roughly two-thirds of Americans reported never having discussed the issue. Interestingly, the same survey showed that Americans are, at least to some degree, aware of their ignorance of science and biotechnology. When asked their understanding of “science and technology” and “biotechnology, genetic engineering, or genetic modification,” 63% rated themselves “poor” to “fair,” 22% rated themselves “good” and only 14% thought their understanding was “very good” to “excellent” (Hallman, Hebden, Aquino, Cuite, & Lang, 2003).
In addition to ordinary citizens, scientists have also suffered due to this educational policy. By concentrating their academic exposure to a specific technical field, they have not been exposed to many important ideas from the social sciences. This may partly explain the glaring lack of participation by scientists in public office in the United States. As of 2007 there were more ministers (6) than chemists (3) in Congress, and there were only 24 scientists out of 535 members, even using the broadest definition of scientist (Schulte, 2007). This is a troubling scenario as decisions made by politicians are increasingly requiring a certain level of scientific literacy to properly evaluate.

**Importance of Science Literacy**

In their 1987 paper titled, *Why Should we Promote the Public Understanding of Science*, Geoffrey Thomas and John Durant proposed nine different reasons why it is important for the public to understand science. Though they wrote of science in general we can analyze these in terms of the importance of physics specifically.

The first reason is the benefit to science itself. Science progresses much quicker in societies that are
conducive to scientific endeavors. When the general populace understands science at some level they are much more likely to support it through public funding and other avenues. This can be seen when one looks at the stagnation of science in Europe during the dark ages after the fall of the Roman Empire and prior to the Renaissance. Also by understanding science the general population has a reasonable expectation as to what science is capable of. This prevents the public from holding scientists to unrealistic standards and the subsequent generation of negative attitudes toward science.

The second reason given is the benefit to the national economy. Thomas and Durant use a capitalistic model of global economics to state that having a scientifically literate populace directly translates to a higher gross national product (GNP) and thus a higher standard of living. This is because in order to compete in a global economy a country will have to produce goods that are the result of a substantial research and development program. These research and development programs rely on an available pool of scientifically trained personnel. By increasing scientific training, this pool of trained people is larger and more effective.
The third reason given is the benefit to national power and influence. The national prestige and potential influencing power of a government partly depends on its scientific and technological achievements. The Soviet Union gained much positive publicity when it was able to manufacture and deploy an artificial satellite before the United States. The United States however, is still reaping the psychological benefits of landing a man on the moon over forty years after the fact. The benefits do not necessarily have to be psychological or political, they can be very tangible. Scientific advances in military technology can translate directly into increased national influence; the primary example would be the U.S. development of the atomic bomb under the Manhattan Project during World War II.

The forth reason for general scientific literacy is the benefit to individuals. The benefits to the individual are manifold. With a scientific background many more employment opportunities are open than would be without any scientific training. This employment gap will only become wider as society increasingly incorporates technology in its vital functions. The benefits to the individual are not merely financial. Without an adequate scientific
background an individual may not be able to navigate through modern consumer society and distinguish the health risks associated with certain products and activities. A current example of this is the primarily unscientific movement in the United States against vaccinations for children.

The fifth reason stated is the benefit to the idea of democratic government. Modern scientific endeavor is usually a very expensive proposition by necessity it requires the assistance of government. Democratic societies are fundamentally controlled through the active participation of the citizenry. If citizens are ignorant about science they will not be able to make informed decisions concerning issues related to science or technology, resulting in possibly harmful legislation. An additional benefit of training in science is the increased logical deductive capability instilled in the citizen, which should result in the election of public officials most advantageous to the populace and planet.

The sixth stated benefit is to society as a whole. Society benefits when science and scientists are incorporated in the social fabric. There is a potential
that science will become isolated from the rest of society due partially to its esoteric nature, and partly because of its specialized practitioners. The problem with this situation is that if the general public begins to view science as a “cult”, then their actions toward it could be damaging to the practice of science.

The seventh benefit is intellectual. Society has placed value on education and its relation to class. If we view a cultured, intellectual person as what people should aspire to, then the dissemination of scientific knowledge is essential to promote the general social improvement of society. When scientific knowledge is reserved as the domain of the elite class, then society will continue to reinforce historic class divisions.

The eighth benefit is the aesthetic. In order to fully appreciate life and nature one should have a certain scientific literacy. Many writers and philosopher have written on the need to appreciate literature, music or the visual arts, science must now be added to the list. Instead of making the world more austere or cold, science has the ability to make it more interesting and beautiful. In an interview for Public Broadcasting Service’s Nova,
Nobel Prize winning physicist Richard P. Feynman eloquently described how knowledge of science can add to the aesthetic beauty of nature,

I have a friend who’s an artist and he’s sometimes taken a view which I don’t agree with very well. He’ll hold up a flower and say, "look how beautiful it is," and I’ll agree, I think. And he says, "You see, I as an artist can see how beautiful this is, but you as a scientist, oh, take this all apart and it becomes a dull thing." And I think he’s kind of nutty.

First of all, the beauty that he sees is available to other people and to me, too, I believe, although I might not be quite as refined aesthetically as he is. But I can appreciate the beauty of a flower.

At the same time, I see much more about the flower than he sees. I could imagine the cells in there, the complicated actions inside which also have a beauty. I mean, it’s not just beauty at this dimension of one centimeter: there is also beauty at a smaller dimension, the inner structure...also the processes.

The fact that the colors in the flower are evolved in order to attract insects to pollinate it is interesting – it means that insects can see the color.

It adds a question – does this aesthetic sense also exist in the lower forms that are...why is it aesthetic, all kinds of interesting questions which a science knowledge only adds to the excitement and mystery and the awe of a flower.

It only adds. I don’t understand how it subtracts (Feynman, 1993).

The final listed benefit of general science education is a moral benefit. It has been argued that science can
lead mankind to a more moral existence by demonstrating the existence of objective truth, and thus countering coercion methods such as appeal to authority or charismatic personal argument that can be used to promote non-desirable human behavior. The study of science can instill in the student a respect for all of nature, and humankind’s proper place in the web of life. This respect may lead to more ethical human behavior in relation to other forms of life and the planet itself. On the other hand, science has come under scrutiny in the past half century in terms of its own ethics, most probably due to the great number of scientists employed in weapons research and manufacture, resulting in a persuasive counter argument to science’s overall positive ethical benefit.

In recognition of the importance of scientific literacy the premier association of physics educators, The American Association of Physics Teachers (AAPT), initiated in 2002 the Physics First approach to education. Through this program the AAPT is hoping to institute a “physics for all” approach to physics education in the United States. AAPT hopes not only to expose more American students to physics, but also to begin teaching it at an earlier age. Instead of waiting until their junior or senior year of
high school, AAPT would like to begin teaching physics as early as the freshman year (American Association of Physics Teachers, 2009). It is believed that this early exposure will help students in their later science studies and perhaps convince more students to enter the scientific field professionally.

Physics will play a central role as we try to balance education between science and the humanities for both scientists and non-scientists alike. Physics is especially important in relation to the other sciences due to its very general nature. The other sciences such as Biology, Chemistry or Geology can be better understood through the application of physics. Physics will be central not only because it is the foremost natural science, but because the study of physics has beneficial effects for the learner in a myriad of ways. The study of physics imparts many skills that can later be applied to situations seemingly unrelated to the context in which they were learned. Such general skills as physical modeling, logical deduction, complex problem solving and estimation are but a few abilities one learns when studying physics that can have a wider range of application (Redish, 2002).
Statement of the Issue

The need to sustain and improve the scientific training of the general workforce has resulted in multiple research studies aimed toward the goals of enrolling more students in science courses and also making those courses more effective. In order for instructors to improve student learning and knowledge retention, it is necessary for the instructor to have as much information concerning the student’s physical science conceptions as possible. This information will allow the instructor to more efficiently use classroom time in dispelling common misconceptions (see Chapter 2 for definition and discussion) and promoting correct physical concepts in the most effective way possible given the students background. Spurred on by the need to understand student conceptions there have been many studies dedicated specifically to discovering what these conceptions are, and many other studies dedicated to schemes to classify conceptions (Palmer, 2001; Chu, Treagust, & Chandrasegaran, 2007; Trumper, 1996; Periago & Bohigas, 2005).

While there has been plentiful research on students’ physics conceptions, the amount of research on how or why
these conceptions are formed is much less complete. Additionally, the vast majority of inventories created to detect student misconceptions rely on a multiple choice answer format. While sophisticated conceptual tests such as the Force Concept Inventory (FCI) have very specifically chosen multiple choice answer categories, there is still a lack of sufficient information on student reasoning. Without this information we can only say if a student has the correct or incorrect concept but nothing on the reasoning the student is using to accept that conception. Even this conjecture is subject to error due to the nature of false positives in multiple choice questionnaires.

Another problem is involved with determining what misconceptions the students actually have. By limiting their answers to four or five possibilities it is possible that the exam is not even addressing the misconception the student has. The answer categories were chosen specifically by the authors of the exam to represent categories they had observed as common misconceptions in their own instruction (Hestenes, Wells, & Swackhamer, 1992). However, it is impossible to cover all the possible misconceptions a student may possess in a finite number of answer categories, thus by default the multiple choice exam
cannot discern all possible misconceptions, only those it was designed to expose. Hestenes et al. correctly recognized this deficiency and stated that the FCI can truly only identify a student using Newtonian thinking and should not be used to identify individual misconceptions, in their words,

“The Inventory questions are only probes for Newtonian concepts, so one should not give great weight to individual items. There are occasional false positives in the responses of non-Newtonians and false negative from Newtonians. But only a true Newtonian generates a consistent pattern of Newtonian choices with an occasional lapse at most. Thus, the Inventory as a whole is a very good detector of Newtonian thinking.” (p. 142)

Thus the FCI does its stated mission of identifying Newtonian thinkers very well, but should not be used to identify other conceptions the students may have.

One undisputed fact stated frequently in physics education research is that students entering a university physics course already have mental conceptions of the interaction of matter and energy. These conceptions are formed through the complicated interplay of academic instruction and sensory experience. Debate has existed for many years on the relative importance of sensory experience versus academic instruction (Palmer, 2001). It would be
beneficial if the importance of academic instruction as it relates to later conceptual modeling could be quantified.

Most of the studies relating to physics concepts have used introductory physics courses for data. Introductory physics courses tend to be populated by students from a wide range of undergraduate programs and academic backgrounds. Although there have been studies describing the identification and/or remediation of misconceptions in pre-service elementary teachers, there have been very few studies that specifically look at their conceptual modeling (Volkmann, Abell & Zgagacz, 2005). Pre-service teachers are a very important group to study due to the nature of their future occupation in teaching. Research has shown that children begin forming conceptual frameworks early in life (Klammer, 1998). Elementary school teachers may have a great effect on the physical conceptions their students form, based upon the examples and explanations they choose to utilize in class. Additionally, there has been comparatively little research on female students’ conceptions of physical phenomena. This is due primarily to the smaller number of female students in standard physics courses. By analyzing pre-service elementary
teachers this research project will primarily examine female students in contrast to other studies.

**Purpose of the Study**

This study is designed to analyze and reveal patterns in students’ conceptual understanding of various electromagnetic phenomena. The answers students give to the individual questions will be studied not only for accuracy, but also for the reasoning behind them. The study will not only provide useful information to both high school science and mathematics teachers, but also to university instructors, physics educators and the students themselves. This study is important because it fills gaps in knowledge, methodology, and demographics in regards to physics education research.

**Significance of the Research**

This research is significant for multiple reasons. By quantifying the correlation between pre-university academic experience and physics conceptions much could be done to improve student learning. This improvement can take place not only at the university level but also in high school. If a university instructor is aware of the average
mathematical and scientific academic background of the students in a particular course it will be possible to change the instructional method to best suit the students enrolled. These changes may consist of altering the course timeline to spend more or less time on particular subjects depending upon the nature and quantity of student misconceptions. The quantification of the relationship between high school academic background and conceptions would also allow the university instructor to pick example and homework problems that would be the most effective to dispel common misconceptions based upon the average high school academic experience of the students enrolled in the course.

Since this study is going to examine a significant quantity of female students, it may reveal some significant issues regarding how female students understand fundamental electromagnetic processes. This may result in a better understanding of how female students process instruction or perhaps how their different experiences prior to instruction manifests in their conceptions of physical processes.
The nature of the content material students are asked to respond to gives one final reason this research project is significant. The majority of published papers on physics conceptions are concerned with mechanics. There are relatively few papers looking at students’ conceptions in electromagnetism. This project aims to cover several topics in electromagnetism and thus add to the literature significantly.

**Introduction Summary**

A common theme of human history has been the continual (with some periods of deterioration) accumulation of knowledge and technical prowess. This progression has been made possible by increasing levels of education among both the intellectual and working classes. The primary educational accomplishment of the past few centuries has been the high levels of literacy seen in all but the most impoverished nations. The goal of the next century needs to be an analogous improvement in scientific literacy for the masses. This is vital because many and perhaps most of the problems facing mankind are of a scientific and technical nature. If the masses are not educated in scientific matters, they will not be able to make informed
decisions on important matters and will not be able to elect qualified leaders due to their naiveté.

Towards the goal of improving science education many research studies have looked at students’ conceptions of various phenomena. These studies have found that students form and maintain many false conceptions regarding not only physics, but all different fields of knowledge. This was discovered primarily through multiple choice exams, such as the Force Concept Inventory (FCI), specifically designed to identify erroneous conceptual thinking. These multiple choice exams however have some deficiencies, and they should not be used to examine individual student reasoning due to their limited response nature.

Generally physics research papers examining student conceptions on the introductory level have a similar subject demographic nature. The previous studies tend to use an introductory non-calculus or calculus based physics course. This normally results in an overwhelmingly male demographic. In addition, very few future teachers fall into this often researched demographic. Future teachers are of special importance because of the future educational impact they will have.
This research paper proposes to address some of the deficiencies of previous studies relating to student physics conceptions. For instance, instead of using a multiple choice inventory to query students, an open-ended questionnaire will be used. This approach will allow the students to represent their mental conceptions by either writing or drawing, instead of limiting their answers to researcher designed answer categories. It is hoped that this methodology will result in new information with regards to what students are actually thinking. This study also proposes to address the demographic deficiencies of earlier studies. The subject group for this research project consists of pre-service elementary teachers and is primarily female. This fact introduces two commonly underrepresented demographic groups into the physics education research literature.
Chapter 2: Review of Literature

For this project the literature review must cover multiple fields relating to the central idea of students conceptions. The history of physics education must be briefly covered, with its current status covered in more detail. In order to understand how students relate to physics generally, it is instructive to review the literature on students’ understanding of the nature of the scientific enterprise. This is reviewed in some detail. Next the method by which enrolled students process data in a physics course must be discerned, with particular attention paid to the difference between conceptual learning and memorization.

Student conceptions, including their origin, longevity, robustness to change, and many other factors, will be covered in extensive detail. Specific student conceptions in areas of importance to the research project will be included. Theoretical frameworks concerning how student conceptions form and change will be analyzed against the published data. Another important area concerning student conceptions is the question of whether
or not there is a gender difference in either conceptual formulation or implementation. Lastly, other issues pertinent to the research project, such as issues specific to pre-service teachers or the relation between high school academic exposure and physics performance, will be reviewed.

**Physics Education Today**

Through the efforts of associations such as the AAPT and countless instructors across the country, physics education has been evolving. The old model of impersonal lecturing is slowly giving way to a multitude of new approaches. The pressure for this change came from two primary sources. First was the need to train a wider variety of students in science for the reasons discussed in Chapter 1. The influx of so many students with differing backgrounds and learning styles stressed the traditional lecture style physics course to the point that many physics education researchers began investigating and implementing radical new ideas of instruction. The second reason was the publication of many studies performed in physics education that demonstrated students did not fundamentally
understand the subject material as well as their academic performance was indicating they did (Hake, 1998).

Traditionally, students enrolled in a physics course were on the path to a career in a technical field. The style of instruction was tailored to this category of student. The material was presented in a manner to set the foundations for more advanced study. The mathematical methods employed were chosen purposely to prepare the student for further study in the field of physics (Redish & Steinberg, 1999). The inherent problems with this instructional scheme made themselves known when, due to the changing views on the need for widespread scientific training, there was an influx of new students with widely diverging social and academic backgrounds. Today it is estimated that approximately 95% of students enrolled in an introductory physics class will never take another physics course in their university career (Rigden, 1997).

The fact that most students will only be exposed to physics for one or two semesters, places great pressure upon the instructor to provide training of lasting impact. Toward this end, many researchers have desired to change the conventional lecture arrangement. Usually introductory
physics courses consist of large lecture classes for 2-4 hours per week. This is normally supplemented with a 2-3 hour weekly laboratory, and possibly a 1-2 hour weekly recitation section. There have been many attempts to modify this generic approach, though most rely on the premise of more instructor-student interaction. A typical example is the approach known as tutorials and promoted by Lillian McDermott of the University of Washington. In the tutorials model the lecture and laboratory sections of the course are kept relatively unchanged. However, the recitation component is drastically altered. Instead of the students watching a teaching assistant solve problems and taking notes, they are put into groups of 3 or 4 persons and complete specially produced assignment worksheets. These assignments allow the students to make predictions based upon their own logical reasoning, and then work the problems out with the help of their partners and the teaching assistant acting as a facilitator (McDermott, Shaffer et al., 1998).

While the tutorials method is a relatively small break with convention, other proposals have completely disregarded the traditional lecture. In their 2002 article published in the American Journal of Physics, David Meltzer
and Kandiah Manivannan describe how they transformed a traditional lecture physics course into an “active learning” environment. Meltzer and Manivannan used the technique of continuous instructor-student interaction. One method employed in their scheme was the use of flashcards. Each student was given a set of flashcards labeled A through F. The instructor then demonstrated multiple physics problems with six possible answers each. The students would then hold up the flash card they thought correlated with the correct answer. This encouraged student interaction and provided the instructor with real time feedback on the status of student knowledge. When employing similar methods today the flashcards have been replaced with electronic classroom communication mechanisms, though the effect is the same. After seven years of development and implementation, Meltzer and Manivannan believe that this style of instruction is practical, effective and possible to implement on a large scale.

Knowledge of the Scientific Process

In order to probe the scientific reasoning used by students when solving or explaining a physics problem, the
proper background must be given. Students have ideas about science in general that can affect the type of reasoning they apply to problems or situations. The most basic student knowledge regarding science is knowledge of the scientific enterprise itself. Following the method of Driver, Leach, Millar, and Scott in their 1996 book, Young People’s Images of Science, student ideas related to the scientific process can be categorized into three different categories.

The first category is students’ views on the purpose of scientific work. There is evidence that students’ understanding of the scientific enterprise evolves with increasing maturity. According to the 1989 article of Carey, Evans, Honda, Jay, and Unger published in The International Journal of Science Education, pre-adolescent students have a different epistemological stance toward scientific inquiry and knowledge than scientifically literate adults. Carey et al. found that pre-adolescents possessed many conceptions of scientific inquiry in contrast to the accepted forms. For instance, when young adolescents were asked to design experiments or draw conclusions from experimental evidence, major deficiencies in approach and reasoning were found. Kuhn and Phelps
(1982) conducted a study in which pre-adolescent students were asked to identify substances in relation to a specific chemical reaction. Kuhn and Phelps found that the students missed the goal of finding out which substances caused the chemical reaction, but instead focused on simply producing the reaction (a color change in this case). This result was interpreted by the authors as confusion in the students’ minds between understanding a phenomenon and simply producing the phenomenon.

Carey et al. also found that pre-adolescents had problems distinguishing between the notions of theory and evidence. This confusion inhibited their ability to either support or refute a theory with applicable data. Driver et al. found that young people have a tendency to have an inductive view of science. Inductive reasoning (also known as inductive logic) is the method of reasoning that produces a general statement of fact from a number of observables. Inductive reasoning is a form of theory building that uses specific observed occurrences to develop a theoretical construct, thus allowing the prediction of future knowledge. The weakness of inductive reasoning is that by formulating a theory based upon a finite number of observed occurrences, there is a certain unavoidable lack
of certitude. An example of inductive logic would be the following statement:

It has always been observed that the sun rises each day in the east. Therefore tomorrow the sun will rise in the east.

While this statement may seem reasonable, there is no way we can be certain that the inference is correct. There always exists a finite probability that the sun may not rise in the east tomorrow.

In contrast to inductive reasoning is deductive reasoning (also known as deductive logic). Deductive reasoning consists of stating premises and forming a deductive argument that is the logical consequence of the premises. Deductive arguments themselves are simply valid or invalid, not true or false. The truth of the conclusion of the argument depends upon the truth of the premises. The validity of a deductive argument depends upon whether the truth of the conclusion is a necessary consequence of the premises and its corresponding conditional is a logical truth. A typical example of a deductive argument is:

| All apples are fruit. |
| All fruits grow on trees. |
| Therefore all apples grow on trees. |
As opposed to inductive reasoning conclusions, there can be complete confidence in the conclusion of a deductive reasoning process if two factors are taken into account. The conclusion of a deductive argument is only as true as the premises. The logical progression must follow valid rules of logic.

Scientists generally use inductive reasoning to develop theories of nature. In simple terms, scientists observe many occurrences of phenomena and subsequently devise theoretical models that not only explain observed data, but can predict other, previously unknown, phenomena. As a prototypical example of the inductive process in science, Newton’s law of universal gravitation can be analyzed. In 1687 Isaac Newton published his law of universal gravitation in order to explain multiple, seemingly unrelated phenomenon (Jones & Childers, 2001). Prior to Newton’s work, Galileo had noticed that all objects fall with the same acceleration regardless of weight (neglecting air resistance). In the early seventeenth century, Johannes Kepler published his three laws of planetary motion which accurately described the motions of the planets (another example of inductive reasoning). Newton was able to take these seemingly
independent observations and devise a theoretical formulation that described all of them. This is an illustrative example of inductive reasoning. Newton’s theory was able to explain all previous phenomenon and predict new observables (such as the presence of the planet Neptune), yet in accordance with the nature of inductive reasoning there was no way to be sure of its absolute correctness. In fact, Newton’s law of universal gravitation eventually proved unable to explain the precession of the perihelion of Mercury and was subsequently replaced by Einstein’s theory of general relativity (Serway, Moses, & Moyer, 1989).

Though inductive reasoning is the primary method of science, there are examples of deductive reasoning. Perhaps the finest example of deductive reasoning is Albert Einstein’s 1905 theory of special relativity. Instead of consciously trying to formulate a theory to explain a disparate number of observables, Einstein instead proposed two premises that he believed unassailable (Einstein, 1905).

I. The Principle of Relativity: The laws by which the states of physical systems undergo change are not affected, whether these changes of state be referred
to the one or the other of two systems in uniform translatory motion relative to each other.

II. The Principle of Invariant Light Speed: Light in vacuum propagates with the speed $c$ (a fixed constant) in terms of any system of inertial coordinates, regardless of the state of motion of the light source.

From these two premises Einstein was able to deduce the framework of the special theory of relativity. The premises Einstein chose, the logical deductions he made, and the conclusions he drew have withstood over one hundred years of scrutiny and are believed to be correct.

The second category Driver et al. used to classify students’ knowledge of the scientific process is the nature and status of scientific knowledge. Here it was found that young children have problems distinguishing between the theory itself and evidence. In addition, Driver et al. referenced experiments that showed young children had a propensity to disregard anomalous data and retain the initial theory. It was also noted that secondary students tend to view science as an impersonal field of simple observations with little creativity on the part of the scientist. In general students’ views of the nature and status of scientific knowledge improved with increasing
age, however, misconceptions persisted throughout each age group.

The third and final category Driver et al. described was science as a social enterprise. It is stated that students tend to view scientists as people that produce products in order to improve mankind. This appears to be the result of confusion between science and technology. Students are divided on whether scientists have been a net benefit to mankind with some students noting the negative effects of some scientific discoveries.

When presented with a science related question, students answer with a wide variety of responses depending upon their education, age, and conceptual model of the phenomenon in question. In an effort to simplify this type of analysis, Driver and her coauthors devised a categorization methodology that allows student epistemological representations to be placed into one of three categories. Table 2.1 describes the attributes of each of the three different categories.
Table 2.1
A Framework for Characterizing Features of Students’ Epistemological Representations.

<table>
<thead>
<tr>
<th>Form of reasoning</th>
<th>Form of scientific enquiry</th>
<th>Nature of explanation</th>
<th>Relationship between explanation and description</th>
</tr>
</thead>
</table>
| Phenomenon-based reasoning | Focus on phenomenon  
- Enquiry as observation of the behavior of phenomenon, i.e. ‘Look and see’  
- Making phenomena happen so that consequent behavior can be observed | Explanation as description  
- Description of phenomenon; no distinction between description and explanation | No distinction  
- No clear separation between description of phenomenon and explanation |
| Relation-based reasoning | Correlating variables  
- Interventions in, or planned observations of, the behavior of phenomena are needed to find explanations.  
  - These involve:  
    - controlled intervention in phenomena, such as fair testing  
    - identification of influential variables  
    - outcomes related to conditions | Empirical generalization  
- Explanation as relation between features of phenomenon which are observable/taken as existing (e.g. heat, vacuum). Such relationships can take the form of:  
  - correlation between variables  
  - linear causal sequence | Induction relationship  
- Recognition that description and explanation are distinct, but both use the same language categories, i.e. refer to features which are observable/taken as existing  
  - Explanation is seen as emerging from data; is expressed in same language categories as data and expresses the relationship between taken for granted features of the situation  
  - The relation between theory and evidence is seen as unproblematic; theories can be ‘proved’ |
| Model-based | Evaluate theory | Modeling | Hypothetico-deductive |
The first category is the phenomenon-based reasoning category. The primary characteristic of this group of reasoning is a lack of distinction between the description of the phenomenon and the explanation of the phenomenon. As a consequence of this, students' explanations when using this type of reasoning generally amount to little more than a restatement of the problem. Consequently, students using...
phenomenon-based reasoning tend to view science as a very dry subject, simply consisting of scientists making and recording observations. As an example of this we can look at the following question; “Why when I drop the ball does it fall to the ground?” Students using phenomenon-based reasoning might state something similar to the following, “The ball fell because you dropped it.” This is just a restatement of the question and does not add any useful information.

The second category is relation-based reasoning. Relation-based reasoning is typified by students making a relational connection, sometimes with a quasi-material agent as an intermediary, between observable features in the phenomenon. Students using this type of reasoning tend to look for only one “cause” to each event and thus are prone to miss important factors involved. Relation-based reasoning usually results in a relatively simple linear cause and effect model being utilized. A relation-based answer to the previous question concerning a dropped ball might be, “The ball fell because the ground attracted it.” Here the student has stated a relation between the cause and effect, namely a force of attraction between the ball and the earth. There is however, no discussion of the
underlying causes for such a force, or any explanation of why the ground attracted it.

The third category is called model-based reasoning. A characteristic of this reasoning model is the clear distinction between the explanation of the phenomenon and a simple description. Unlike the other two categories, the language used in explanation is different from the language of the problem itself. Students using this type of reasoning tend to be aware that theories are dynamic entities, open to revision and replacement if necessary. People using this reasoning also tend to be aware that theory creation is a creative process and not simply the result of observation. A student answering why the ball fell to the ground using model-based reasoning might state the following, “The ball fell because due to the masses of the ball and the earth there is an attractive force between them as described by Newton’s law of universal gravitation. The ball begins falling when the upward force of the hand is removed and the net force on the ball due to gravity is directed downward and thus the ball accelerates downward.” The important point is that the student is trying to give some reasoning as to why the ball falls, instead of simply stating it does fall.
Although there exists a hierarchy of complexity from phenomenon-based reasoning through relation-based reasoning to model-based reasoning, this does not necessary imply a hierarchy of student cognitive ability. The authors state that depending upon the situation, any particular category may be appropriate. The authors did state that with increasing student age they noticed a movement up the complexity scale of reasoning. This scale should also not be used to categorize an individual student’s reasoning ability, because it is possible for the same person to use different types of reasoning depending upon the context or type of problem they are presented with.

Driver’s et al. categorization of reasoning can be used to classify students’ responses to individual questions. This is an effective way to quickly categorize student responses for further analysis based upon their level of complexity in reasoning. While it is understood this type of categorization may not result in detailed cognitive information on individual students, it can result in interesting and useful data concerning groups of students.
Student Learning in Physics

Historically the extent of student learning has been judged through the use of a summative assessment at the end of each section of material. Research has shown that this standard assessment, traditionally consisting of the student solving a number of problems mathematically, is not necessarily representative of their fundamental understanding of physical concepts (Wieman & Perkins, 2005). In fact, students are able to learn how to solve problems mechanically, through memorization of techniques, without increasing their knowledge of the essential processes taking place in the problem. This reliance on conventional testing evolved, at least partly, due to the efficiency and objectivity it presents to instructors. Logistically it is not possible to ascertain the conceptual knowledge of each student in a large introductory physics course. However, due to advances in physics education research, instructors are now able to write examinations that delve more deeply into the conceptual knowledge of the student, and are less likely to be answered correctly through sheer memorization of classroom examples and problem solving techniques (Hestenes, Wells, & Swackhammer, 1992).
In order to promote critical thinking over rote memorization, physics researchers are recommending instructors stress the importance of physics concepts and conceptual thinking to students. It has been shown in multiple studies that even after completing a physics course a students’ knowledge of the fundamental concepts covered is generally poor (Ambrose, Shaffer, Steinberg, & McDermott, 1999). Conceptual knowledge is especially vital in physics because it is almost impossible to remember how to solve all the different problems and situations one may encounter. If students understand the underlying concepts connecting different phenomenon, they will be able to derive the correct approach to all related problems. Students have been able to avoid a deep conceptual knowledge base by memorizing most of the different situations to be covered on one particular test. The ability of students to retain this information over the long term is notoriously poor, especially when they have to memorize a whole set of new situations for the next examination. If students would instead gain a deep conceptual understanding they would not only perform better on examinations, due to their ability to adapt the same concept to different situations, but would retain what they
have learned longer due to a smaller amount of information needing to be memorized (Mayer, 2003). In order to promote conceptual learning in students it is necessary to understand how this type of learning evolves.

**Student Physics Conceptions**

It is well accepted in the physics education research community that students bring a whole set of conceptions with them into their first university physics course. There is however no real consensus on what form that body of knowledge takes. Do students’ preconceptions form a coherent structure similar to a standard scientific theory, or are they more comparable to an assortment of ideas and conjectures without unifying themes? It has been argued by some researchers that student conceptions are organized and interrelated, resulting in a theoretical structure similar to primitive explanations of phenomenon such as Aristotle’s theories concerning dynamics and motion (McCloskey, 1983; Sequeira & Leite, 1993). Conversely, some researchers believe that misconceptions of physical phenomenon are formed out of a very fragmented knowledge base (DiSessa, 1988). In addition to these two there is a third view that consists of a combination of the previous two. Researchers
have stated that classification of naïve student conceptions may not be as simple as two distinct classes; their conceptions of some phenomenon may resemble a scientific theory, with their conceptions of other phenomenon consisting of various unorganized thoughts and ideas (Mildenhall & Williams, 2001). These same researchers have found that the subject of mechanics in particular is one in which people tend to form a more coherent theoretical framework. As stated by other research scientists, Mildenhall and Williams found that the mechanics framework of naïve students closely mirrored the ancient impetus theory of Aristotle.

**Origin of student conceptions.** The conceptions students have when they arrive to their first physics class were formed over the course of their entire life. In fact, many of the conceptions students have are the direct result of their interaction with the physical world (diSessa, 1988). The interaction between a person and the natural world is mediated by the various sense organs. We learn through what we see, feel, hear, and to a lesser extent taste. Children learn very young that fire is hot, ice is cold, objects need to be push or pulled to move, rocks fall faster than feathers and a host of other observable
phenomenon. Driver (1983) promoted the notion that children function as “scientists” because they have a natural tendency to hypothesize about various phenomena. From Driver’s perspective, science and the scientific method have only formalized what exists in human nature naturally.

Before children enter kindergarten they have constructed a cognitive framework of how the world operates. Studies have shown that even prior to their first birthday, children have a basic knowledge of important physical principles such as conservation of mass (Klammer, 1998). An infant’s awareness of conservation of mass was demonstrated by letting a child watch an object slide through a skeleton framework first, then covering the framework so the object “disappeared” as it was slid through and monitoring the child’s reaction. Researchers noticed a distinct emotional response from the child when the object seemed to temporarily disappear.

Language is also an important factor to look at when discussing where students’ conceptions originate. Humans use metaphors to help process new events and place them within existing knowledge frameworks (Lakoff & Johnson,
1980). In essence, when we witness a new event such as a computer software failure we have not encountered before, we tend to analyze it based upon a software failure we have encountered in the past and proceed toward a solution accordingly. According to Lakoff and Johnson the use of metaphors to incorporate new ideas is not limited to developing minds, but is used by everyone, including experts in their respective fields. The inherent problem with metaphors is that many times, though they may seem accurate superficially; they do not fully translate between the two phenomenons.

A typical example of misplaced metaphor from physics is the Bohr model of the atom. The Bohr model of the atom is one of many atomic models proposed in the early twentieth century by physicists and chemists in their attempts to understand the dynamics of atomic structure. Niels Bohr developed his model of the atom in 1913, through the use of classical, and some primitive quantum physics (Serway, Moses, & Moyer, 1989). The Bohr model of atomic structure utilizes a solar system metaphor. According to this model, electrons are little spheres that travel in perfectly circular orbits around another small sphere, the nucleus. The electrostatic attractive force between the
positively charged protons in the nucleus and the
negatively charged electrons in orbit around it provide the
needed centripetal acceleration to maintain a stable orbit.
In this metaphorical approach the sun is represented by the
atomic nucleus, the planets are represented by the
electrons, and the gravitational force is represented by
the electrostatic force.

The current understanding of atomic structure is very
different from this solar system based theoretical model.
Instead of distinct planar orbits, the electrons are now
thought to exist in spherical probability clouds in the
space around the nucleus. In addition, there are many
quantum mechanical attributes to atomic dynamics (such as
quantized angular momentum, electron spin, radioactive
decay, the Pauli Exclusion Principle, emission and
absorption of electromagnetic radiation, etc.) that cannot
be explained using a simple solar system metaphor.

This example demonstrates both the advantages and
disadvantages of the metaphorical approach to learning.
The distinct advantage of this approach, and possibly the
reason humans have evolved to use it so proficiently is its
inherent efficiency. By assimilating new phenomenon
through metaphor we are able to understand new situations very quickly. This most likely had great survival value in our evolutionary history. The downside to the metaphor approach, as was demonstrated with the Bohr model of the atom, is that many times it is not entirely applicable. This can lead to possible misunderstanding or over simplification of physical principles. Another possible negative aspect to metaphorical learning is that it can limit the human mind’s ability to discern and interpret new details because it can constrain thought processes to a previous theoretical framework.

Conceptions formed throughout childhood and early adulthood may serve an important survivor function, but they are not always technically correct. When people hold conceptions of physical phenomena that are contrary to currently accepted scientific theory, these are generically labeled misconceptions. Throughout educational research literature on misconceptions there have been many terms used to discuss erroneous conceptions, including; alternative conceptions, preconceptions, naïve conceptions, alternative frameworks, naïve beliefs, naive theories, common sense conceptions, and many others. ‘Misconception’ will be the common term used in this article, with the
other terms being viewed as synonyms unless specified differently. Unfortunately, not only do students bring many misconceptions with them into the classroom, it has been demonstrated through research that students tend to hold on to their misconceptions even after instruction, even when the instructional methods used were specifically devised to alleviate misconceptions (Clement, 1987). Misconceptions not only prevent the students from correctly solving problems, they also affect a student’s interpretation of all concepts being addressed by the instructor. For example, Resnick (1983) found that misconceptions students held caused them to misperceive laboratory and classroom demonstrations.

Within the research literature on misconceptions some researchers have investigated whether certain misconceptions were universally applied, or if there is a contextual basis for their application. Previously some researchers have asserted that misconceptions were generally applied. For example, if a student held a misconception on Coulomb’s force law it would be revealed in any contextual environment as long as the problem required Coulomb’s force law to solve (Allbaugh, 2004). In this 2004 research paper, Alicia Allbaugh investigated
whether students’ conceptions of Newton’s laws of motion depended upon the context of the problem being asked, or if they were contextually independent. Allbaugh asked students several questions relating to Newton’s laws of motion with only the context differing, not the fundamental physics. When this experiment was performed, she recorded vastly different answers based upon the question context. Allbaugh found that when the problem involved diminishing forces, for instance an electrically charged object being accelerated by another stationary charge, the students reverted to the Aristotelian misconception of impetus. However, when the problem did not involve a diminishing force, the students used the more correct Newtonian conceptual model. This research implies that perhaps people use different conceptual thinking for the same physical phenomenon based upon contextual cues.

The failure of our naïve conceptions is most obvious in the study of modern physics. Albert Einstein’s 1905 theory of special relativity and his subsequent 1916 theory of general relativity are notoriously counterintuitive. The idea of space, mass, and time varying depending upon ones relative velocity is not at all obvious to the human mind. The combination of space and time into a four
dimensional Lorentzian manifold, and its curvature due to mass and energy are also not easily comprehended by the human mind. The other major branch of modern physics, quantum mechanics, is also highly counterintuitive. In this field we have to accept ideas such as fundamental indeterminacy, wave-particle duality, and quantization of energy and momentum. Once again, these ideas are not to be found in the naïve human mind. However, we do not need to look to modern physics to find conceptions that are fundamentally flawed; the most basic physics is rife with incorrect student conceptions.

The most basic concept in physics is that of substances, or equivalently, matter. Students possess many conceptions concerning what substances are and how they interact. In their extensive study of the conceptual understanding of children regarding substances, Miriam Reiner, James Slotta, Michelene Chi and Lauren Resnick listed eleven concepts they believe students have regarding substances.

- Substances are *pushable* (able to push and be pushed).
- Substances are *frictional* (experience “drag” when moving in contact with some surface).
- Substances are *containable* (able to be contained by something).
• Substances are consumable (able to be “used up”).
• Substances are locational (have a definite location).
• Substances are transitional (able to move or be moved).
• Substances are stable (do not spontaneously appear or disappear).
• Substance can be of a corpuscular nature (have surface and volume).
• Substances are additive (can be combined to increase mass and volume).
• Substances are inertial (require a force to accelerate).
• Substance are gravity sensitive (fall downward when dropped).

(Reiner, Slotta, Chi & Resnick, 2000, p. 5)

These substance attributes are learned early in life and are fairly persistent. These notions concerning substances are the genesis of many incorrect conceptions students hold in physics.

Student conceptions of mechanics. Of all the topics in physics few have been more studied with regard to student conceptions than mechanics. In introductory physics courses, mechanics is primarily limited to Isaac Newton’s three laws of motion. These laws, published as part of Newton’s Principia Mathematica in 1687, are as follows:
I. Everybody persists in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by force impressed.

II. The change of momentum of a body is proportional to the impulse impressed on the body, and happens along the straight line of which that impulse is impressed.

III. To every action there is always an equal and opposite reaction: or the forces of two bodies on each other are always equal and are directed in opposite directions.

The first two laws describe the reaction of objects to applied forces. The third law is a statement about the nature of forces and is effectively a statement on the more basic conservation of momentum principle. Physicists view forces as being due to interactions between material objects. For instance, the electromagnetic force is a result of the interaction of two electrically charged objects just as the gravitational force is the result of the interaction between two massive objects. The common contact force as when pushing or pulling a macroscopic object is actually the large scale manifestation of the electromagnetic force.
One of the most commonly held scientifically
unacceptable conceptions concerning the mechanics of force
interactions is the idea that force is not the result of
interacting bodies, but is in fact an extensive property of
the objects in question (McCloskey, 1983). This naïve
theory implies that objects are kept in motion by an
internal force instead of an external force. According to
this approach, when someone throws a javelin into the air
they are putting force into the object which continues
within it during the duration of its flight. In this type
of theory, force is something that can be contained within
an object, transferred to other objects or even transformed
(Kikas, 2003).

Erroneous conceptions concerning mechanics are so
frequent with students that specific tests have been
created by physics education researchers to quantify them.
The two most used are the Force Concept Inventory (FCI) and
the Mechanics Baseline Test (MBT). The FCI test is a
multiple choice test designed to discern the specific
conceptions students may have in mechanics, specifically
relating to Newtonian forces (Hestenes, Wells &
Swackhammer, 1992). This is done by a very deliberate
choice of questions and possible answers based upon
research into common student conceptions. Each question in the FCI requires the student to choose between a Newtonian concept of force and one or more “common sense” incorrect alternatives. By including convincing distracters for students using incorrect theoretical models the authors believe the test can signal potential student misconceptions.

The FCI has multiple potential uses, but the primaries are as a diagnostic tool, a placement exam and to evaluate teacher effectiveness. The FCI can be used as a diagnostic tool because it very effectively identifies and classifies certain student misconceptions. This can be used by teachers to evaluate their students’ knowledge at the beginning of the semester. The authors recommend that the test be supplemented with verbal interviews in order to uncover the reasoning the students are utilizing.

The FCI can also be used as an evaluator of instructor effectiveness. This is usually done by giving the test on the first day of instruction and then again at the end of the semester (pre/post test methodology). The scores for each student are then compared to see the amount of improvement. The change in scores is then compared to the
average expected gain in order to evaluate the particular instructor. The authors state that the pretest is usually unnecessary because “the pretest scores are so uniformly low for beginning physics students that further pretests are really unnecessary, except to convince diehard doubters or to check out the conceptual level of a new population” (Hestenes, Wells, & Swackhamer, 1992, p. 150). The authors state that research shows low posttest scores cannot be blamed on the background of the student but are most likely the result of the instruction. One potential problem with using the FCI as an evaluator of the instructor is the possibility of “teaching to the test.” If the instructor is aware of the impending evaluation, the nature of the course may change in order to concentrate on similar force type problems in order to improve student scores.

The FCI can also be used as a placement exam. The FCI should be used in this format to see if introductory university students have the conceptual underpinnings sufficient for more advanced coursework. This particular use of the FCI has been under some scrutiny because it has been argued that there exists uncertainty in what the FCI actually measures, so to use it as a placement exam would be unfair to students (Huffman & Heller, 1995).
The MBT test is a very similar exam to the FCI but was created to be given to students after they have completed their college level physics course. The MBT analyzes mechanics concepts that would not be available to someone without formal knowledge of mechanics. The MBT also covers a larger aspect of mechanics than just Newtonian force, with concepts such as energy conservation and work being included.

While the FCI and MBT are used to diagnose possible misconceptions there is also research into classifying student misconceptions by type. The Comprehensive Conceptual Curriculum for Physics program headed by Richard Olenick (2009) created a list of common student misconceptions concerning Newton’s Laws:

- Action-reaction forces act on the same body.
- There is no connection between Newton’s Laws and kinematics.
- The product of mass and acceleration, ma, is a force.
- Fiction can’t act in the direction of motion.
- The normal force on an object equal to the weight of the object by the 3rd law.
- The normal force on an object always equals the weight of the object.
- Equilibrium means that all the forces on an object are equal.
- Equilibrium is a consequence of the 3rd law.
- Only animate things (people, animals) exert forces; passive ones (tables, floors) do not exert forces.
• Once an object is moving, heavier objects push more than lighter ones.
• Newton’s 3rd law can be overcome by motion (such as by a jerking motion).
• A force applied by, say a hand, still acts on an object after the object leaves the hand.

This list is by no means comprehensive; however it does cover many of the most commonly seen misconceptions.

**Student conceptions of light.** Another content area of physics students are known to have erroneous conceptions is light and geometric optics. Following the methodology of Reiner, Slotta, Chi, and Resnick in their 2000 article published in *Cognition and Instruction*, misconceptions about light can be divided into four separate categories.

The first category is the idea that light acts as a fluid, meaning it can flow and come to rest. Studies have demonstrated that students tend believe inaccuracies such as light will come to rest if shone upon a piece of white paper (Guesne, 1985). This idea that light can come to rest on an object is a manifestation of the light acting as a fluid conception.

The second category is that light mixes in a manner similar to liquids. Nearly all students have had experience mixing paint colors and they try to apply these
concepts to the mixing of light of different colors. The primary physical difference here is that mixing paints is known as subtractive color mixing, while mixing light is additive color mixing. The distinction between subtractive and additive color mixing can be seen when we mix all of the colors of the spectrum together. If this is done with paint we will get a very dark brownish color, however if this is done with light we will get a white light. Students overwhelmingly use their previous knowledge of mixing paints when discussing the mixing of light, thus reinforcing the view that they picture light as a fluid (Olivieri, Torosantucci & Vicentini, 1988).

Another misconception common to light and optics is the idea that light creates friction upon contact with material objects. This idea most commonly manifests itself in the belief that air creates friction for light in the same way that it would for a baseball, football, or other material object. Along the same line of reasoning, students have a tendency to believe that a frictional force exists between different rays of light when they interact spatially with each other (Stead & Osborne, 1979).
The last category is that light, colors and shadows are inherent properties of an object. This is a very common misconception seen at all levels of human cognitive development. When a physicist observes a red apple, he knows that the apple only appears red because it is effectively absorbing the non-red frequencies of the electromagnetic spectrum and reflecting the frequencies the human brain perceives as red (wavelength of approximately 670nm). When a novice sees a red apple they believe the apple “really” is red, that color is an inherent property of the object and not the result of a complex material interaction with light (Apelman, 1984). Other studies have shown that people believe shadows have an independent existence from light (Feher & Rice, 1986). In the study of Feher and Rice, many subjects believed that shadows would continue to exist even in total darkness. This is due to a misunderstanding on how shadows are created in relation to light beams.

Students have also been found to exhibit misconceptions when dealing with the reflection of light from mirrors. In their 2002 article to the Journal of Experimental Psychology, Camilla Croucher, Mario Bertamini, and Heiko Hecht analyzed students’ ability to correctly
determine reflection characteristics from plane mirrors. Previous research studies have found that surprisingly many students and adults believe in an extramissive theory of vision (Cottrell & Winer, 1994). An extramissive theory is one in which the student believes that something, presumably light, shoots out of the eyes in order to visualize objects. Research into naïve student conceptions on mirrors is relevant because it is assumed students have had daily experiences with mirrors since a very young age. Due to these frequent interactions students will have created a conceptual framework on the mechanics of mirrors. Misconceptions that students have formulated concerning reflection of light and general optical phenomenon are referred to as naïve geometrical optics.

Croucher, Bertamini, and Hecht distributed a questionnaire to students asking when they thought certain objects would be visible in plane mirrors. The situations varied in the direction the object of interest approached the mirror, and in the relative mirror size. The respondents consistently overestimated what would be visible in the plane mirror. Surprisingly, this overestimation persisted even when the students were allowed to enter and investigate an actual room such as
depicted in the questionnaire. The authors proposed four theoretical explanations for the poor student performance in geometric optics. The first is that the students exhibit an egocentric bias when they conceptualize mirrors. In other words, they instinctively feel that even if the mirror is mounted flatly on the wall, it must be angled slightly toward them when they view their reflection. The second possible explanation is that the mirror functions as a type of camera. In essence, the students may believe that the mirror captures an image of whatever is directly in front of it. This misconception is related to the creation conception, in which the student believes the mirror has an inherent ability to create images similar to a television.

The authors call their third explanation the boundary extension hypothesis. This hypothesis states that students will tend to overestimate what a mirror reflects in an analogous manner to what has been found in studies of student representations of photographs (Intraub, Bender, & Mangels, 1992). The boundary extension hypothesis predicts a psychological or perception phenomenon in which the human brain tends to fill in some visual data around the edges of an image. The author’s last possible explanation has to do
with a perceived left-right reversal in plane mirrors. The common perception that a mirror flips left and right may explain some of the confusion the authors discovered on certain questions. This misconception is extremely common throughout society, but is not considered correct in the physics community. The more proper explanation is that the mirror flips the image along the front-back axis, resulting in an apparent left-right switch in addition to other effects (Feynman, 1983). Even though the authors were unable to explain all the different misconceptions they found within a single coherent theoretical framework, they were able to classify the common misconceptions in this little investigated field.

**Student conceptions of electricity.** When we look at the field of electricity and magnetism we see that many people maintain a false conceptual framework. A basic understanding of electricity and magnetism (electromagnetism) is especially important for students today because of the immense importance of electricity in modern society. Electromagnetism is also of utmost importance to the field of physics as it is one of the known fundamental forces of nature. Protons and electrons are the elementary carriers of charge in nature. A proton
is defined to carry a positive charge while the electron carries a negative charge of equal magnitude. Charges of opposite nature attract each other, while charges of similar nature repel each other. The electric field generated by these charges extends away from the charge indefinitely, while getting weaker with increasing distance.

Electrical circuits provide a common example of electromagnetism in action. The electrons themselves are the charge carriers when current flows through the circuit. Commonly a battery provides the potential energy and the assorted circuit elements provide some resistance to current flow. The basic relationship between current, voltage and resistance in a simple direct current circuit is, Voltage = Current * Resistance (V = IR), known as Ohm’s Law after nineteenth century German physicist Georg Ohm (1789 – 1854).

While ancient people most likely would have viewed electrical phenomenon as mystical or even magical, we expect modern students to have much familiarity with it. Since a very young age students have been switching electrical circuits on, using flashlights, plugging
electrical appliances into wall outlets, and hearing about electricity. However, in spite of this supposed familiarity, students have been shown to have multiple misconceptions concerning electromagnetism. Electrical current itself is the source of much confusion. While physicists view electric current in a conducting wire as the slow drift of unbound electrons under the influence of an electric field, novices have a wide range of explanations for this phenomenon.

Studies have found that young students generally do not visualize electric current as distinct particles in motion, instead they tend to view current as some sort of energy wave or spark (Kibble, 1999) A common explanation seen in many research studies on the topic (Cohen, Eylon, & Ganiel, 1983; Fredette & Lockhead, 1980) is that current is a substance which previously existed in the battery and when connected to a circuit this substance is released to travel through the wires and is then consumed by the lamp or other device. Interestingly, many of the misconceptions of electricity and magnetism observed in the student population can also be found in middle school science teachers (Pardhan & Bano, 2001).
Following the methodology of Reiner, Slotta, Chi, and Resnick in their 2000 paper, we can categorize naïve conceptions of current into three separate models. In the first model, known as the unipolar model, the electrical current leaves the battery on one wire and is then subsequently consumed by the connected device. In this model there is no need for a wire from the device back to the other battery terminal; in essence there is no complete circuit necessary. The second model is known as the clashing current model in which current flows out of the battery from both terminals and clashes at the device in order to operate it. The last model is the attenuation model in which students believe current flows from one end of the battery, through the device where some of it is used up, and then back to the other battery terminal through the connecting wire.

In addition to electric current there are also misconceptions concerning the nature of “voltage,” which is more properly known as “electric potential difference,” a term which denotes the potential energy per unit charge in a given electrical configuration. A chemical battery is rated at a certain voltage depending upon its internal construction; however, naïve views of voltage usually
center on the physical size of the battery and how this relates to the rating in volts. Many students have a tendency to believe that voltage is a measure of how much current exists in the battery, both of which are flawed conceptions. Using this type of erroneous logic, many students believe that a battery with a higher voltage rating will always last longer under similar usage than one with a lower voltage rating (Reiner & Shauble, 1988). In an effort to correlate their ideas of voltage with their conceptions of current, some students see voltage as a property of the current (Reiner, Slotta, Chi & Resnick, 2000). Confusing matters even more, research studies have also found that students used the physically distinct terms current, voltage, energy, power and electricity interchangeably when discussing electrical circuits and currents.

In a 2007 article published in the *International Journal of Science Education* Shyan-Jer Lee analyzed students alternative conceptions pertaining specifically to batteries. Batteries are devices that convert chemical energy into electrical energy. Generally a battery will consists of multiple voltaic cells connected together in order to produce the desired voltage. The electric
potential is created through a reduction-oxidation chemical reaction within the voltaic cells. Students are expected to have formed conceptions concerning chemical batteries due to their inevitable contact with them from an early age.

When Lee surveyed primary school student conceptions about batteries, a variety of misconceptions appeared. Many students were confused as to what was physically inside the battery. Some students stated that the internal cavity was filled with an iron block or magnetic particulates. Other students believed that the battery must have consisted internally of many tiny wires or coils. Some students even believed that the battery was only filled with invisible electricity. When asked to describe the flow of current through a circuit connected to a battery the students repeated many of the same misconceptions that Reiner et al. (2000) discussed in their paper.

A significant portion of the students believed that positive charge exited the positive terminal of the battery and negative charge exited the negative terminal of the battery and these opposing charges collided at the light
bulb (or other circuit element) causing it to glow. When the students were queried about what was occurring when a battery became weak and ineffectual, most believed that the current which had previously resided in the battery had been “used up” by the connected circuit elements. When the students were asked to discuss the power of the battery, they consistently correlated this with the physical dimension of the battery itself. Following the findings of Kikas (2004), Lee ascribes most of these misconceptions to linguistics. Lee believes the common terminology used by laypersons in discussing batteries foments the creation of misconceptions regarding their physical properties.

Studies have also demonstrated that misconceptions concerning electromagnetism are common regardless of the age of the students. Studies have shown that even advanced physics students with exposure to modern physics curriculum retain fundamental misconceptions, which can lead to incorrect assumptions and conclusions regarding electrical phenomenon (Redfors & Ryder, 2001). A 2005 study by M. Cristina Periago and Xavier Bohigas from the Polytechnic University of Catalonia found that second year undergraduate engineering students retained many
misconceptions concerning electricity. The authors found several of the previously discussed misconceptions in this cohort of more advanced students; Periago and Bohigas listed the most significant discovered misconceptions as;

- A battery is a source of current that supplies the loads that travel round a circuit.
- A battery always provides the same current regardless of the circuit to which it is connected.
- The current supplied by the battery ‘is used up’ as it flows round the circuit.
- Potential difference is a consequence of the flow of current and not its cause.
- Incorrect application of Ohm’s law (p. 75).

Current electricity is not the only subfield of electromagnetism filled with student misconceptions. The more basic field of electrostatics, even though less researched, also has its share of misconceptions. A fundamental misconception researchers have repeatedly found is that students believe a neutral object must be devoid of all charge (Thacker, Ganiel, & Boys, 1999; Baser & Geban, 2007). This is a misconception because a neutral body is electrically neutral not because of a lack of charge, but due to equal amounts of opposite charge. This type of misconception is also seen in a common student statement concerning capacitors. Many students hold the belief that
a “charged” capacitor contains a net charge (Sanger, & Greenbowe, 1999). This is fundamentally erroneous. A capacitor is a physical device used to store energy by charging two plates oppositely. While each plate may be charged negative or positive, the capacitor itself is still neutral, as charge is merely separated.

Another common naïve conception within the field of electrostatics is that some students believe charged objects only contain either protons or electrons. In other words, students believe a positively charged object has many protons and no electrons, while a negatively charged object has many electrons and no protons (Baser & Geban, 2007). Nothing could be further from the truth, both positively and negatively charged objects contain protons and electrons, the only difference being their relative amounts. The transfer of electrostatic charge also lends itself to misconception. Students have been found to believe that metal objects cannot transfer charge if they are both charged with the same sign (either positive or negative), that there is no transfer of charge between a charged metal object and a neutral metal object, and that any two metal objects of opposite charge will both become neutral upon contact (Guruswamy, Somars, & Hussey, 1997).
Theories of Conceptual Evolution

An important consideration in the study of conceptual models is their robustness. Students’ conceptions are notoriously difficult to change for a multitude of reasons. The conceptions students bring to the classroom are the result of a lifetime of interaction with the environment. This environmental interaction continues during the students’ instruction and can continue to promote erroneous conceptions. Due to these factors student misconceptions have been found to be stable, robust, and highly resistant to change (Anderson & Smith, 1987).

Some researchers have broken misconceptions down into two categories, fragmented and coherent (diSessa, 1988). Fragmented misconceptions are conceptions that result from a set of loosely connected ideas, while coherent misconceptions result from a consistent, understandable pattern of ideas. diSessa (1998) believes that the intuitive understanding of physics principles can be broken down into fragments he calls “phenomenological primitives” or p-prims. A p-prim is just an abstraction of what a particular individual experiences in nature. Using this framework, the impetus theory of antiquity would simply be
the manifestation of the p-prim of “continuous force” (Clement, 1982). Simple misconceptions may be represented by one category of p-prim while more complicated misconceptions are more likely the result of several interacting p-prims. In contrast to the fragmented model of misconception is the coherent model. In the coherent framework, misconceptions are viewed as more theory-like explanations. This was initially uncovered because of the similarity in modern physics misconceptions and pre-scientific theories of natural philosophy (Chi, 2005).

Research has suggested that certain physical misconceptions are more robust than others (Hestenes, Wells, & Swackhamer, 1992). In her 2005 article to The Journal of Learning Sciences, Michelene Chi proposes that misconceptions can be placed into two different ontological categories in order to determine their robustness or longevity. According to this theory, conceptions that do not match reality on the ontological level, called emergent, will tend to be robust. In contrast, alternative conceptions within the same ontological category as the correct conception, called direct, will be easier to correct. Chi proposed different instructional techniques for each category of misconception. If the student is
suffering from a direct misconception, then conventional learning processes such as refinement of existing beliefs will be sufficient to correct it. However, if the student is suffering from an emergent misconception then the student will require additional psychological steps in order to correct their belief. These additional steps will consist of making the student aware of their faulty ontological reasoning and then construct the proper theoretical structure for acceptance of the correct conception.

There is the additional problem of the psychological mechanics of new knowledge incorporation. When students are faced with new knowledge they tend to incorporate it into existing frameworks instead of creating new ones (Baser & Geban, 2007). In order for students to disregard their previous knowledge framework they need to be confronted with a sufficient reason to change (Hewson & Hewson, 1984). This infers a type of Darwinian struggle for the survival of concepts in individual minds. According to Calvin (1998), people continually generate conceptions of physical phenomena which are then evaluated against competing concepts for their value in problem solving, with the conception demonstrating the greatest
problem solving utility being retained. Similarly, in his 2001 paper in the *International Journal of Science Education*, Keith Taber promotes the theory that conceptual development results from the competition between alternative conceptions. Taber states that conceptual development is a long term process in which shift from conception to conception is a slow evolutionary process instead of a quick one. According to this approach, students will typically hold both the old and the new conceptions simultaneously, and as they become more comfortable using the new concept they will begin employing it more and eventually phase out the old conception. However, this evolutionary process can be very temperamental; if the student receives negative feedback regarding the new conception, they can disregard it for the old. Toward this end, instructors need to bridge the gap between the old and new concept slowly and deliberately. In the words of Vygotsky (1986), the instructor needs to place activities within the learner’s “zone of proximal development.”

Swiss epistemologist Jean Piaget stated that the necessary conditions for conceptual change are disequilibrium, assimilation and accommodation (Piaget,
1950). Under this theorem in order to create new conceptual frameworks a student must first enter a state of cognitive disequilibrium, which occurs when the student cannot assimilate new physical phenomenon or ideas into an existing conceptual framework. Once disequilibrium has been achieved, the student can mentally construct a new conceptual framework using the process of accommodation. In accordance with this method, instructors should confront students with phenomenon that cannot be explained under naïve theoretical frameworks in order to achieve disequilibrium and thus a fertile learning environment.

Many researchers and educators have proposed methods to create cognitive conflict in students and promote new conceptual learning along the line Piaget suggested. One of the most influential conceptual change methods proposed was introduced in 1982 by G. J. Posner, K. A. Strike, P. W. Hewson and W. A. Gertzog in which the learning process was broken down into four steps consisting of:

1. There must be dissatisfaction with existing conceptions. Scientists and students are unlikely to make major changes in their concepts until they believe that less radical changes will not work.
2. A new conception must be intelligible. The individual must be able to grasp how experience can be structured by a new concept
sufficiently to explore the possibilities inherent in it.  

3. A new conception must appear initially plausible. Any new concept adopted must at least appear to have the capacity to solve the problems generated by its predecessors.  

4. A new concept should suggest the possibility of a fruitful research program. It should have the potential to be extended, to open up new areas of inquiry (p. 214).

According to Piaget it is important that students’ conceptual framework be challenged in some sense similar to this, or it is risked that the new information they are being introduced to will be incorporated into their previous framework and the result will be a hybrid of beliefs, ranging from correct to incorrect. Historically, physics instructors have not performed a satisfactory job of challenging students’ naïve conceptual framework because numerous studies have found that even advanced physics students retain many incorrect concepts (Baser & Geban, 2007). Klammer (1998, p. 14) stated that the majority of students “spend their time in most physics courses justifying existing knowledge rather than learning the process of discovering knowledge.”

**Expert/novice approach.** Since experts in particular fields are known to process problems conceptually, one way
to discover how conceptual thinking is attained is to analyze the differences in how experts and novices approach problems. In a groundbreaking study conducted in 1965, Dutch psychologist Adriaan de Groot analyzed chess players of varying strengths to distinguish the difference, if any, in their thought patterns. Surprisingly to de Groot, he found that both master level and amateur level chess players approached chess problems in a very similar manner, each went through a four step process consisting of, an orientation phase in which the subject assessed the position and at most developed a general strategy, an exploration phase in which the subject explored tactical options at some depth, an investigation phase where the subject explored the favored move at maximum depth, and finally a proof phase which consisted of checking the preferred move for any hidden or unseen dangers. Writing about the similarities and differences he saw, de Groot stated:

We know that increasing experience and knowledge in a specific field (chess, for instance) has the effect that things (properties, etc.) which, at earlier stages, had to be abstracted, or even inferred are apt to be immediately perceived at later stages. To a rather large extent, abstraction is replaced by perception, but we do not know much about how this works, nor where the borderline lies. As an effect of this replacement, a so-called 'given' problem
situation is not really given since it is seen differently by an expert than it is perceived by an inexperienced person... (p. 33-34).

This research into chess players demonstrated a more fundamental truth about learning, namely how experts and novices process data.

Experts in a particular field do not necessarily think differently, only more efficiently. Experts use an efficient method of utilizing historically similar patterns to process new information and situations. This has direct application to teaching students a conceptual approach to physics. Expert physicists solve physics problems in a manner very similar to how master chess players analyzed positions in de Groot’s experiment. The experienced physicist looks for underlying concepts that are similar between two different problems. This allows new problems to be solved based upon a relative few important concepts, and makes memorizing numerous equations superfluous. We see a very opposite approach by novice physics students. When confronted with a new problem they try to conjure up an appropriate equation out of their memory bank of numerous equations. This is a highly inefficient method of solving physics problems due, not only to the large number
of equations a student would have to remember, but also because they would have select the one or two that correctly fits each particular problem. This is no small feat as completely different physics equations contain many of the same variables, and the correct equation may only differ from an inappropriate equation by only a single term or sign. It is analogous to memorizing the roots to as many quadratic equations as possible and trying to recall them when prompted, as opposed to just memorizing the quadratic formula and knowing when to properly apply it. Unfortunately, even when novice physics students do try to employ conceptual models to help them solve problems, they tend to focus on the superficial aspects of the problem, such as the object involved, rather than fundamental, deep features, such as energy conservation (Kohl & Finkelstein, 2008).

In their 1980 Science article, Larkin, McDermott, and Simon stated that another difference between novice and expert problem solvers was their progression of reasoning. The experts would usually follow a scheme that begins with a pictorial representation of the problem, continued to a physical representation that included any pertinent forces, and concludes with a mathematical representation. The
novice problem solvers were much less consistent in their methodology. Some would begin with mathematical equations and then move to pictures, while others would skip certain phases altogether. Even when novice problem solvers obtained the correct physical or pictorial representation they tended not to transition to the mathematical representation correctly.

However, experts not only differ from novices in problem solving, they also organize their subject knowledge differently (Bransford, Brown, & Cocking, 2000). Experts have been shown to organize their knowledge in physics around several major themes or ideas. These major themes are effectively equivalent to the major concepts mentioned above. Novices tended to store information in a more disorganized manner. In addition, novices placed undue attention to superficial aspects of previous problems they had encountered instead of the underlying similarities between them. Within the field of physics this results in experts utilizing general ideas such as conservation of energy or mass, while novices are more likely to view each problem as separate and unique.
**Constructivist approach.** In their 1993 article to *The Journal of the Learning Sciences*, Smith, diSessa, and Roschelle articulated a constructivist perspective on transitional knowledge. The authors stated that research on misconceptions in science had been very productive but had perhaps misinterpreted the data. Prior to the inception of research on misconceptions, researchers tended to sort student answers into two categories, correct or incorrect. With the advent of misconception theories, researchers began to analyze the nature of the answers students presented. This resulted in many insights into the psychological process of learning. The authors stated that research into misconceptions had resulted in seven primary theoretical commitments.

The primary thesis of misconception research is that students have misconceptions. Today this notion may seem trivial, however prior to research on misconceptions, many investigators subscribed to the Lockean idea that students could be viewed as tabula rasa, or blank slates. It is now generally assumed that students arrive to class with their own individual conceptions of physical phenomenon, which they use to explain the natural world. In order to fall into the category of misconceptions, the conceptions
students have must fundamentally differ from expert conceptions and thus systematically produce erroneous results.

The second assertion of misconception research is that misconceptions originate in prior learning. Students synthesize their conceptions based upon their interaction with nature and their previous academic training. Depending upon the nature of the material, either academic or environmental factors are dominant. For instance, with ideas about force and motion, environmental interaction tends to be more important than academic training (McCloskey, 1983; Resnick, 1983). However, when we look at mathematical conceptions, academic interaction has been found to be more important (Resnick, Nesher, Magone, Omanson, & Peled, 1989).

The third assertion of misconception research is that misconceptions can be stable, resistant to change, and widespread among students. This is in contrast to rapidly produced thoughts that are just as rapidly disregarded when confronted with conflicting data. Misconceptions are formed over longer periods of time and have shown much stability even when explicitly demonstrated to be erroneous.
by instructors. Misconceptions have also been shown to be widespread among the student population (Taber, 2001). They are not simply flawed conceptions held by a few underperforming students.

The fourth assertion of misconception research is that misconceptions interfere with learning. Due to their pervasiveness and robust nature, misconceptions have been shown to inhibit the assimilation of new knowledge (Hestenes, Wells, & Swackhamer, 1992). Helm (1980) found that student held misconceptions can negatively affect learning across many different disciplines in physics.

The fifth assertion of misconception research is that misconceptions must be replaced. In essence, the naive misconceptions students have must be disregarded and replaced with expert concepts. Contained within this view of replacement is the implicit notion that misconceptions are completely useless, and dispelling them entirely has no discernable negative effects.

The sixth assertion of misconception research is that instruction should confront misconceptions. In essence, for students to overcome their old misconceptions and replace them with the preferred expert conceptions, the
instructor will have to confront the misconception directly. This implies a very conscious effort on the instructor’s part to explain the difference between the expert concept and the common misconception, not just teach the correct conception. This process should be ideally initiated by the student stating their misconception, the instructor showing inconvertible proof of its invalidity, and finally the instructor elucidating the correct concept. In order for confrontation to produce the desired result, the students must internalize the differences between their misconception and the expert conception.

The last assertion of misconception research according to Smith, diSessa, and Roschelle (1993) is that research should identify misconceptions. The authors assert this, not due to explicit statements in the literature, but due to deduction from the nature and distribution of the research on misconceptions. Since the inception of this line of research, the majority of published papers have sought to document misconceptions in a variety of different academic disciplines and contexts. The authors state that much less research has been conducted on the evolution of misconceptions, learning processes, and instructional remedies to misconceptions.

- 86 -
Smith, diSessa, and Roschelle believe that although misconception research has provided much useful information to education theory, the conclusions drawn have not been entirely correct. They propose that the evolution of misconceptions can best be analyzed through a constructivist framework. Constructivism is a psychological theory in epistemology that stresses direct experience in learning. Importantly, in the theory of constructivism, people build new knowledge on the superstructure of old knowledge. One of the primary proponents of constructivism was Jean Piaget, expressed through his ideas of assimilation and accommodation. The central thesis of the authors is that misconception research has produced results that are in fundamental disagreement with the tenets of constructivism. If the results of general misconception research are correct, then it is difficult to accept that such misconceptions can serve as the foundation for the future construction of expert opinions. Generally misconception research, specifically the expert-novice framework, has stressed the difference between expert concepts and naïve concepts. According to constructivist theory, this gap must be bridged by a continual refinement of conceptual knowledge.
In order for this approach to work, there must be some knowledge of value inherent in the original naïve conceptions. The authors use the term ‘resources’ to designate any feature of the older naïve conceptual mode that can serve as useful input in the process of conceptual growth.

The constructivist theoretical framework states that there exists productive knowledge in the naïve conceptions students possess. This is especially true for the more robust student misconceptions. This does not infer that all student conceptions are useful in the construction of expert knowledge; it is supposed there are many conceptions that are useless and do not figure into the evolution of conceptual knowledge. The idea that there exists valuable knowledge in student misconceptions is one of the primary differences between the conventional view of misconceptions and the constructivist view. This has lead constructivists to analyze contexts in which naïve student conceptions are productive, instead of only contexts in which they fail to produce useful data.

The constructivists suggest that there are two fundamental problems with the conventional view that
misconception replacement is a one-for-one process. Conventionally, misconception replacement has meant that students begin using the correct conceptual viewpoint at the same time they disregard the old incorrect conceptual framework. The first problem the constructivists have with this viewpoint is the basic simplicity of it. For this approach to be applicable, the misconception has to be a unitary, independent cognitive structure. In contrast, researchers have found that the relationship between cognitive structures is complex (Kuhn & Phelps, 1982). In addition research has shown that students can switch between correct and incorrect conceptual models during the same problem solving session, suggesting that a one-to-one replacement model may not be complete (Clement, 1982).

The second problem the constructivists perceive with the one-to-one concept replacement model is that it is antithetical to their premise that learning is the continual adaptation of previously held knowledge. With regards to this problem, Smith, diSessa, and Roschelle (1993) state:

The critical question raised by replacement is: What prior knowledge is involved in the construction of the expert concepts that replace misconceptions? If we accept the mistaken character of misconceptions, they cannot
serve as resources. The other possibility is that students have some complementary pool of productive knowledge that can be brought into competition with misconceptions, but misconceptions researchers have not identified such resources within the novice understanding” (p. 125).

Through the development of their theory of conceptual change the constructivists also critique the confrontational method of instruction many times promoted by other misconception researchers. The confrontational method of instruction works from the premise that students’ naïve conceptions need to be confronted directly and explicitly by the instructor in order to foment conceptual change. It is postulated that when demonstrated the superiority of the correct conceptual model, the students will disregard their old notions and adopt the new model enthusiastically. The authors concede that this method of instruction has its benefits and is useful, however they believe that confrontation is an implausible explanation for the changing of conceptual models. This is because if we use the confrontational method there is no way for the students to decide between the two competing conceptual viewpoints because this type of comparison requires criteria for judgment. These criteria must be created from existing knowledge, a situation that the
confrontation/replacement theory cannot account for. Another problem the authors detail concerning the confrontational approach to conceptual change is the psychological effect it can have on a student’s self image. By continually demonstrating the error in their thinking, students may begin to feel that their ability to understand physical phenomenon is fundamentally flawed. In addition, if performed incorrectly the confrontational approach can result in less student-instructor interaction and an overall decrease in classroom efficiency.

Thus it can be seen that misconceptions are an important field of study, not only in physics or science, but in epistemology generally. In order to properly understand and evaluate students’ performance in the field of electromagnetism, it is imperative that an understanding of the nature of misconception be utilized. By studying how misconceptions are initially formed, evolve, and are overcome, instructors are better able to present material and evaluate student performance. Research into misconceptions, both in physics and other fields continues to produce new and interesting results. It is hoped that eventually larger theoretical frameworks will condense out of the varying research in the field, and the resulting
improvement in understanding will translate into better informed students and instructors. The advent of sophisticated computer software that is capable of simulating many different physical phenomena is an area of intense research with regards to student misconceptions. It is believed that by presenting students with accurate visual representations of physical phenomena, students will actively replace their prior misconceptions with more correct expert-type conceptions. Although computer simulation holds much promise for improvement in the field of student misconceptions in physics, it will only be successful if it is implemented using the multitude of findings of misconception researchers during the last few decades.

**Gender Differences in Conceptions**

While most studies choose to analyze students’ physics conceptual models through a gender neutral lens, there exists research on potential differences in the conceptual models used by males and females. Issues of gender inequality in education have been studied for years, with studies of gender inequality in the Scholastic Aptitude Test (SAT) being particularly notable. Gender inequality
in physics must be seriously considered because of the overwhelming number of men in the field compared to women. While women receive 57% of bachelor degrees each year in the United States, only 22% of physics bachelor degrees are awarded to women. The discrepancy gets worse at the doctoral level, with only 14% of physics doctoral degrees going to women, while women attain 44% of all doctorates awarded each year (National Science Foundation, 2002).

It has been found in studies that male and female students tend to perform better when questions are framed in a context familiar to their particular gender (Buck, Kostin & Morgan, 2002). As a consequence of these studies, the context of physics problems must be reconsidered to try and neutralize any gender bias.

As previously mentioned (see Chapter 2), the Force Concept Inventory (FCI) test was specifically developed to discern common student misconceptions; however in the original paper there was no mention of possible gender bias due to contextual framing (Hestenes, Wells, & Swackhamer, 1992). When analyzing the results of the FCI test, there has been a notable gender gap in performance, with males scoring significantly higher (McCullough, 1996).
In 2004, a revised version of the FCI was written, in this particular version all the male-centric contexts were changed to be female-centric, while maintaining the same fundamental physics properties (McCullough, 2004). When this different version of the FCI was given to a sample of students the results changed. The average score of the female students did not significantly change. However, the average score of the male students dropped significantly. When a question by question analysis was performed on the results, it was noticed that the female students did show significant improvement on certain problems, while performing similarly to the standard FCI exam in others.

The gender analysis of the FCI brings to light an important aspect of designing physics problems for students. Not only do the problems have to be designed to reliably test pertinent content knowledge, they must also be written to eliminate or reduce gender and cultural bias as much as possible. In this regard cultural bias refers to biases associated with certain cultural assumptions made concerning students knowledge. For instance, a question that references American football may not be appropriate for a student from another country that is unfamiliar with the sport, or the equipment used to participate in it.
Generally speaking, physics problems should use standard, gender neutral and universally known contextual formats whenever possible.

There is some research that shows men and women may inherently differ on how they construct conceptual frameworks with regards to physics. In a 2008 *Educational Psychology Review* paper, Gita Taasoobshirazi and Martha Carr employ a novice-expert theoretical framework to explain possible conceptual differences between males and females. When expert-novice problem solving ideas are applied to gender analysis we see that females and males approach problems differently. Females tend to memorize facts and try to apply them to problems based upon previous experience (Kahle & Lakes, 1983). This type of approach is very similar to the novice approach. By using memorization females may have a more poorly organized knowledge structure than their male counterparts. This may possibly explain why females are able to perform as good as or better than males in early science classes, but fall behind in secondary school and college courses (Taasoobshirazi & Carr, 2008). Males have been found to be more conceptual in their approach, which more closely resembles the expert method. If the authors are correct and females retain
inferior conceptions when compared to males it may be noticed through the open ended questionnaire instruments being employed in this research project.

**Pre-Service Elementary Teachers**

There exists research into many facets of pre-service elementary school teachers, however the area that concerns this report is the relationship between their conceptions and how it may affect their future teaching. Studies have shown that teachers are generally unaware of their students’ misconceptions, due in part to the fact that they themselves also had and still have the same misconceptions (Berg & Brouwer, 1991). This lack of understanding students’ conceptual difficulties leads many teachers to believe that their students’ poor performance is a reflection of the students’ lack of interest or mathematical competency instead of poor conceptual understanding (Caillods, Gottelmann-Duret, & Lewin, 1997). It has been shown in studies that if teachers do not have a fundamentally sound conceptual model themselves they will fail to not only recognize misconceptions in students, but may even confuse correct explanations for misconceptions (Halim & Meerah, 2002). Other researchers have found that
teachers many times fail to consistently correct students’ misconceptions because they are unaware of current research into teaching strategies for dealing with alternative conceptions (Berg & Brouwer, 1991). It is crucial that future teachers have some fundamental understanding of the correct conceptual model of physical process to help prevent them from inadvertently passing their faulty ideas to their students. Research has found that if future teachers succeed in their own academic careers without having to learn proper concepts, they will tend to pass this erroneous method of learning onto their own students (Lortie, 1975).

Pre-service elementary teachers are an interesting demographic to study also because of the overwhelming number of female students compared to males. By studying pre-service teachers a significant addition to the existing knowledge base can be achieved due to the natural underrepresentation of females in standard introductory physics courses.

**Success in College Physics**

Success in college physics depends upon a great number of factors, some of which are under student or instructor
control, and many which are not. One factor that has an
effect on the success of the student in college physics is
their high school education. While there is much debate on
how great this effect is, most researchers will concede
that it is not insignificant.

Researchers have looked at many aspects of the high
school experience in search of correlations to university
performance. Many of these are not directly pertinent to
this research project and thus will not be closely
described. For instance, in their 2006 article Tradition
and Block Scheduling for College Science Preparation: A
Comparison of College Science Success of Students Who
Report Different High School Scheduling Plans, Kristen
Dexter, Robert Tai and Philip Sadler investigated whether
the type of scheduling students had in high school affected
their subsequent performance in college science courses.
The primary distinction made in the article was between
traditional and block scheduling. The authors found that
the type of scheduling had little to no advantage in terms
of college performance.

Another study looked at whether or not high school
science class size had an effect on college science class
performance. This study found that the positive effect of small class size was insignificant until the class size reached under approximately 10 students, after which there was a positive correlation between smaller high school class size and university science performance (Wyss, Tai, & Sadler, 2007).

The attribute most commonly thought to affect college physics performance is exposure to high school physics. Many studies have been carried out to identify and possibly quantify this supposed correlation. Some studies have found a positive correlation between exposure to high school physics and university physics performance (Hart & Cottle, 1993; Alters, 1995). On the contrary other studies have found that taking high school physics, even advance placement versions, had little to no effect on university level physics performance (Champagne & Klopfer, 1982; Au & Sharma, 2007). Some of these same studies found that the best predictor of university level physics success was in fact the nature of the students’ naïve conceptions before instruction (Au & Sharma, 2007).

In their 2001 comprehensive study of the relationship between high school academic experience and college physics
success titled, *Success in Introductory College Physics: The Role of High School Preparation*, Philip Sadler and Robert Tai improved on many of the previous studies. This improvement was achieved by utilizing a multiple regression analysis model and controlling for multiple demographic and environmental factors. In addition to improving the analysis methodology, Sadler and Tai sought to give both students and teachers advice on how they could best prepare for the transition from high school physics to university level physics.

Sadler and Tai found that there was a positive correlation between taking high school physics and subsequent performance in college physics. However, the correlation they found was only about one-half of what previous studies had found. They attribute this decrease in effect to the inter-correlated nature of independent variables. For instance, there is a high level of correlation between students taking high school physics and high school calculus. Previous studies were not able to distinguish if high school physics exposure, or perhaps another correlated variable such as high school calculus, was causing the increase in college physics performance.
Sadler and Tai found that the nature of the high school physics course was important. Students from classes in which the instructor covered relatively few topics in depth performed better than students from high school physics courses where the instructor covered more material, but in a less rigorous manner. The authors also found a strong correlation between high school math preparation and success in college physics. This correlation was strong enough that students with a strong math preparation, yet no high school physics exposure, can perform as well as students that took high school physics. Sadler and Tai also found that other high school science courses, specifically biology and chemistry, correlate with improved university physics performance, though rather weakly. Other interesting correlations uncovered by Sadler and Tai are, students tend to perform better in physics if they are the same gender as their instructor, students tend to perform better in college physics if they wait to take the course until their sophomore or junior year of college, and that classroom demonstrations do not seem to increase learning if used more than once per week.

Though exquisitely done, the study of Sadler and Tai did have some shortcomings. One potential problem with the
study was that it was not longitudinal. The authors relied on the students to accurately represent their high school academic experience years after the fact, including minor details such as the instructors teaching style. This is pertinent because instructor methodology can have effects on student knowledge absorption and retention (Wieman & Perkins, 2005). Another potential problem is a possible selection effect due to the voluntary nature of the research. Sadler and Tai used data from 19 different professors that volunteered to share this data with them. The nature of voluntary participation in such a study lends itself to selection effect problems. Lastly, Sadler and Tai based the success of college physics purely on grade performance. As we have seen previously (see Chapter 2), students may be able to perform well academically yet not actually understand the material at an acceptable level.

Review of Literature Summary

Physics instruction has advanced greatly from the days of impersonal lecturing and all male students. Today the field is a dynamic area of educational research, with instructors experimenting using various techniques in order to improve student learning. It has been shown over the
past few decades of research that student learning in physics is a very complicated, convoluted process with multiple intersecting variables of importance. The increased pressures of larger enrollment and less homogeneous student demographics have amplified the need for instructors to employ the most efficient methods of instruction.

The nature of students’ beliefs of the scientific process is both interesting and important; research has shown that most students do not have an accurate understanding of the nature of scientific inquiry. When students fail to understand the nature of a theory or explanation it generally follows that their own explanations lack rigor.

Many researchers have examined the nature of students’ conceptions in physics. It is believed that by studying student conceptions researchers can better understand how students are thinking and thus propose more efficient pedagogical techniques. Conceptions of physical phenomenon are formed well before students even enter school. These naïve conceptions are refined continually for the rest of their lives. Physics instructors have the obligation to
correct any conceptions students have that are erroneous and replace them with more correct, scientific conceptions. This process can be extremely difficult, as many studies have shown, due to the robust nature of concepts learned over an entire lifetime.

Students have conceptions, and many times misconceptions, in every area of physics. The pertinent areas for this research project are electromagnetism and to lesser degree Newtonian mechanics. The student conceptions in Newtonian mechanics are important because misconceptions here can lead directly to misconceptions in electromagnetism. When analyzing misconceptions in electromagnetism it is important to know if they are unique to this field, or merely manifestations of misconceptions the students may have in Newtonian mechanics.

There have been many theories proposed to explain and predict how student conceptions are formed and evolve. Only two are looked at in any detail for this project. The two examined here are the expert-novice approach and the constructivist approach. The expert-novice theoretical framework uses the observed differences in how experts and novices approach and solve problems to explain the
acquisition of knowledge. The constructivist approach uses the idea that all knowledge acquisition builds upon previous knowledge frameworks, and thus retains some of the earlier concepts.

There is some research on the nature of gender differences in student physics conceptions. Some researchers have suggested that males and females process information differently and thus form different theoretical frameworks regarding physical phenomena. This study hopes to investigate this further due to the large number of female students in the subject pool. Another underrepresented demographic group to be studied in this research project is pre-service elementary teachers. Pre-service elementary teachers are highly underrepresented in physics education studies because of their low participation in physics courses. This demographic is especially important because of their future profession and the ramifications their beliefs can have on their future students.

Lastly, several factors were analyzed that may or may not lead to success in college physics courses. Multiple studies indicate that exposure to physics in high school
has a positive effect on future college physics course performance. Other factors were also found to have a positive effect on college physics performance, including, high school mathematics courses, high school science courses (non-physics), and other factors such as parent education level. This study is interested in how these same factors might affect students’ conceptions of physical phenomenon, and not just their grades.
Chapter 3: Methodology

Research Methodology

For this research project a number of university students answered three conceptual physics questions in order to permit analysis of the quality of their results, and the nature of their associated mental framework. Their answers to these questions and the theoretical framework they used were then analyzed based upon the nature of their high school education, and other demographic data to discern the possible relation between these independent variables and the students’ conceptions.

This methodology was chosen for multiple reasons. A primary reason for using this approach was feasibility. The principle investigator was the scheduled instructor for the introductory physics course the potential subjects were enrolled, thus providing uncomplicated access to a substantial participant pool. The questionnaire method was chosen because it is a very robust method if implemented properly. For this particular research project an open-ended type questionnaire was used. The open-ended
questionnaires provided an ideal format for the students to explain their rationale for each answer they provided. In the words of Redfors (2001), “These findings lead us to suggest that in order to fully characterize student understanding in a specific concept area, studies need to provide individuals with multiple opportunities to articulate explanations...” (p. 1297).

Post interviews with students were not feasible for this project due to the large number of subjects in the data pool, and only one investigator. However, future research might include student interviews as a means of validating the questionnaires and elaborate on the classification categories.

Research participants. The research subjects for this particular project were all students at Ball State University during the spring semester of the 2009 – 2010 academic school year and were predominantly pre-service elementary education majors. Ball State University is a fully accredited public doctoral/research university of approximately 20,000 students and 1000 faculty located in Muncie, Indiana (Ball State University, 2009). Ball State University offers a professional undergraduate degree
program in elementary education which leads to a bachelor’s degree and one of the Indiana state teaching licenses. As a part of the 126 semester hours for a bachelor’s degree in elementary education, the students were required to take a course on physical concepts. Students seeking an all-level special education license in the state of Indiana also take this course.

The particular course in physical concepts at Ball State University is known internally as PHYCS 101 or Physical Science Concepts for Teachers. PHYCS 101 is a 15 week, three credit hour course, which consists of two lecture periods per week of 50 minutes each. In addition to the lecture periods, the students were required to register for a two hour, once per week laboratory section. The Ball State University website (Ball State University, 2009) describes the PHYCS 101 course as:

Principles and concepts of the laws of nature involving mechanical, heat, light, electrical, nuclear, and chemical energy and the conservation laws associated with these forms of energy. Emphasizes applications appropriate to the classroom. Designed primarily for students in elementary education programs. A total of 3 hours of credit may be earned.

The students in this course varied in academic progression from freshman all the way to seniors. Two sections of
PHYCS 101 are taught per semester with each course having a maximum enrollment of 72 students for a maximum total of 144 PHYCS 101 students per semester. Historically the majority of the class is female, with only approximately 10 - 15% male enrollment. The actual number of participants, defined as students responding to at least one question, for this research project was 135 students. Of the 135 participating students, 11 were male, corresponding to approximately 8% of the class. This was slightly lower than historical averages for this course. Due to the use of human participants this research project was reviewed and approved by the Institutional Review Board (IRB) at Ball State University under IRB #147970-1.

**Research procedure: Day one.** During the first day (January 11, 2010) of the 2009-2010 spring semester, a short recruitment script (Appendix 1) was read aloud by the principle investigator to all the students in both sections of PHYCS 101. This procedure occurred in the designated meeting room and time for this course. The lecture room for PHYCS101 was CP92, a theater styled auditorium in the Cooper Science Building of Ball State University campus. The purpose of this recruitment script was to notify the students of the research project taking place during the
semester. The students were informed that if they signed the consent form, several of their assignments on electromagnetism would be used to analyze student conceptions.

After the advertisement was read aloud and any student questions were answered, the demographic survey sheet (Appendix 2) was handed out. This survey was a single page document that consisted of a list of standard demographic questions and multiple other questions concerning their high school education experience. The survey instructed the students to document their high school education, specifically the courses they took relating to the sciences. The potential list of courses included physics, mathematics, chemistry, geology, biology, earth science, anatomy, and physiology. In addition, questions were asked of students about their career goals and subject matter they planned to teach.

After the students completed and returned the demographic survey document, the principle investigator began the traditional first class meeting lecture. The demographic survey forms were then retained by the principle investigator in a locked file cabinet residing in
a locked office, and were not viewed until the semester ended and final grades were turned in.

**Research procedure for questionnaires.** The PHYCS 101 courses proceeded after the first day in the same manner as previous semesters. The course progressed through the standard course syllabus covering kinematics, Newton’s laws, waves, sound, reflection, refraction, and then color. The students were instructed on the fundamental relations of reflection and refraction, including but not limited to the laws of specular reflection and Snell’s law. Students were taught the simple rules of additive color combination and subtractive color combination. This included instruction on the nature of primary and secondary colors and the nature of human vision. At no time were the students explicitly told “what is happening” on the atomic level during these interactions.

After the students completed the study of reflection, refraction, and color, they received the questionnaire titled, “How do you picture the transmission, reflection, and absorption of light?” The students were given approximately 20 minutes to answer the three questions asked on the sheet (Appendix 3).
The next topics covered in the course were the laws governing electrical current. The students performed simple experiments with electric current and were expected to know Ohm’s Law. At no point in the instruction were the students given an explicit explanation of what is physically occurring within a wire when there is current flow. At this point, the students were given the questionnaire titled, “How do you picture electrical current in a simple circuit?” The students were given approximately 20 minutes to answer the three questions asked on the sheet (Appendix 4).

Next the students more closely looked at the concept of electrical resistance. This included a laboratory exercise with resistors. The students were not given any explanation of the causes of electrical resistance, or why certain resistors exhibit greater resistance than others. At this point in the semester the students were given the final questionnaire titled, “How do you picture electrical current in a resistor?” The students were given approximately 20 minutes to answer the questions asked on the sheet (Appendix 5).
This completed the data acquisition portion of the research project. After collection the three questionnaires were counted as part of the student’s grade for the course. The principle investigator gave all students that turned in the questionnaires credit for completing the assignments. After collection the papers were stored in a locked file cabinet in the principal investigator’s office.

The course then continued for the final weeks in the same manner as in previous semesters. On the last day of class a consent form (Appendix 6) was distributed to all students present. The consent form was a two page document summarizing the nature of the research project. This document informed the potential student participants of their rights as a participant, and other important information, such as the contact information of the principal investigator and the faculty advisor. The students signed the form if they chose to participate, or did not sign it if they wanted to exercise their right to decline participation. In either case, the forms were returned to the principle investigator at this time, but were not viewed until course grades had been turned in.
The students received no further contact from the principle investigator regarding the research project.

**Data handling.** After the students completed the three questionnaires, the principle investigator had all the data required to begin analysis. As previously stated, the data were stored in the principle investigator’s locked office within a locked file cabinet. In order to protect the confidentiality of all participants, names are not to be used in any portion of this report. In order to facilitate the analysis and discussion, a scheme was devised to identify individual response sheets. In order to do this without compromising confidentiality, a random number generator was used to assign numbers to each student. The principle investigator retains the key to this code in a computer spreadsheet file. This file was stored on a password protected computer within the locked office of the principle investigator and at the principle investigator’s residence.
Data analysis. The data were analyzed using an array of techniques ranging from qualitative to quantitative (see Chapter 4 for full data analysis). The data were classified initially on a question by question basis. In other words, the questions were analyzed independently. A further analysis looked at all the questions of each individual student together.

One classification methodology that was applied to the question responses was the epistemological representation categorization devised by Driver and others and previously discussed in Chapter 2. These three categories provided some general information into the type of cognitive approach the students were using. The categorization applied equally well to each question and was performed by the principle investigator. After the questions were categorized this way, associations were investigated comparing categories with academic data. Using the supplied academic information data were tested for significant relationships.

A second type of categorization that was applied to the data was the type of misconception represented. With each separate problem there are a host of common
misconceptions (see Chapter 2) published in the literature. The data generated in this research project were classified according to demonstrated misconceptions. This produced varying numbers of categories for each question. These classifications were also tested for any significant associations with academic data.

The data were also analyzed in terms of what concepts the students demonstrated. This particular analysis has been used in previous studies to evaluate student work (Pardhan & Bano, 2001). This type of classification follows a hierarchical model. With this analysis one proceeds from very broad concepts, to more specific ones. For instance, on the current electricity question the analysis may proceed as follows; concept of electrons, to concept of moving charge, to concept of conservation of charge, etc. The number of responses falling into each category were then analyzed quantitatively. Once again the results of this categorization were analyzed against academic data.

The data were evaluated loosely in terms of “correctness” as well. In order to do this a couple of different approaches were tried. A normative approach was
initially used. This method was used by Redfors (2001) in coding data for a similar electromagnetic question. This method consisted of creating multiple categories ranging from correct response to no response. The responses were then categorized accordingly. Another possibility here was to use more categories than Redfors, with a gradual shift from correct to incorrect. This method was ultimately decided upon as the most applicable to this data set.

When comparing these classifications to final course grade in search of associations a test for statistical significance must be used. In order to test if these percentage differences are significant, a normal distribution for student grades will be assumed. Even though the empirically obtained data curve is only approximately normal, through application of the central limit theory it is deemed unnecessary to employ non-parametric methods of analysis. The manner of analysis performed will be a large sample ($N_{tot}>100$) approach (Healey, 2005). The null hypothesis in this case is that there is no difference between the populations from which the samples on the trait (i.e. mean final grade) are being tested. The equations used are the following:
\[ Z(\text{obtained}) = \frac{(X_1 - X_2) - (\mu_1 - \mu_2)}{\sigma_{x-x}} \quad (\text{Eq. 3.1}) \]

Where \((X_1 - X_2)\) is the difference in the sample means, \((\mu_1 - \mu_2)\) is the difference in the population means, \(\sigma_{x-x}\) is the standard deviation of the sampling distribution of the difference in sample means. Because of the null hypothesis, the \((\mu_1 - \mu_2)\) term reduces to zero. So the equation reduces to.

\[ Z(\text{obtained}) = \frac{X_1 - X_2}{\sigma_{x-x}} \quad (\text{Eq. 3.2}) \]

Next we use the pooled estimate method to calculate the \(\sigma_{x-x}\) value.

\[ \sigma_{x-x} = \left( \frac{s_1^2}{N_1 - 1} + \frac{s_2^2}{N_2 - 1} \right)^{1/2} \quad (\text{Eq. 3.3}) \]

For this analysis we will employ the standard 95% confidence interval \((\alpha = 0.05)\) resulting in a \(Z(\text{critical})\) value of \(\pm 1.96\).

**Limitations.** As in any study there were limitations to be aware of. Even though the sample size was large relative to other studies, it was still too small for generalization to all represented demographic groups. The
demographic groups that were best represented were pre-service teachers and female students.

With only three questions it was difficult to generalize the results to electromagnetism as a whole. As with any analysis of this nature, subjectivity is a major concern. Much of the analysis involved the discretion of the principle investigator and thus was not strictly reproducible. It was also possible that the questions selected may have had some undiscovered bias that could influence the analysis. This was hoped to be prevented by the implementation a test run of questionnaire distribution during the fall semester of 2009-2010. The data produced from this testing was analyzed to determine the questionnaires ability to discriminate expertise among the respondents and determine what range of concepts were usually mentioned could be collected using the procedure described by Ke, Monk, and Duschle (2005). From this test run revisions were made to both the current and resistor questions. These revisions consisted of rewording the instructions and modifying the pictorial representation of both questionnaires. The light question was not revised based upon the test run.
Initially it was planned to perform a gender analysis in order to determine possible relation between student conceptions and gender. This was deemed unfeasible due to the statistically small number of male student questionnaires available for analysis. Instead of quantitative analysis only general statements concerning gender and performance will be made.

**Questionnaire Forms**

As previously stated this research project consisted of administering and analyzing three questions relating to physics generally and more specifically electromagnetism.

**Introduction to the questionnaires.** The three questions used for this project were chosen specifically in order to address areas of physics in which instructors and researchers have reported student difficulty in conceptual understanding (Ege, et al., 2007; Lee, 2007; Pardham & Bano, 2001). Aside from the conceptual construction of the questions, there were other considerations to be taken into account. Since the research subjects were primarily female it was critical to ensure that the questions did not present a gender bias in their contextual framing (Buck, Kostin, & Morgan, 2002). Toward this end, the questions
were written in a gender neutral context as much as possible.

There were other constraints on the question formulation as well. In order for the students to be able to complete the questions in the prescribed amount of time (roughly 15 minutes), it was necessary to keep the questions concise. For the questions to produce useable data, it was imperative that the students answer the specific question asked and not in any way become confused as to what was being asked of them. Accordingly, each question was written as succinctly and unambiguously as possible. In order to reduce complications or confusion, each question followed the same general format. An additional method employed to reduce possible confusion was the verbal reiteration by the principle investigator of the written instructions.

The three different questionnaires were presented on three different days, determined by the progression of the course with regards to subject matter. The total number of students enrolled in the Physics 101 course, and thus potential candidates for participation, was 135. Since the questionnaires were presented on different days, the
response rates were not exactly the same for each question, though close enough for comparative analysis (see Figure 3.1).

![Figure 3.1. Number of students responding to each question.](image)

**Light question.** The first question administered to the research participants was the question titled “How do you picture the transmission, reflection, and absorption of light?” The question is reproduced in Appendix 3 exactly as it was administered to the participants.

For this particular question, the participants were asked to explain why certain wavelengths of light would be reflected, transmitted, or absorbed when incident on three
different objects. The first case consisted of a light wave containing red, green, and blue components striking a piece of transparent colorless glass. The second case consisted of a light wave containing red, green, and blue components striking a piece of transparent blue glass. The third case consisted of a light wave containing red, green, and blue components striking a piece of blue painted wood.

In each case the student was to perform two primary tasks. The first was to illustrate what was physically occurring in each of the three scenarios. In order to facilitate this process, a representative piece of glass was drawn for the students on the worksheet. It was hoped that the student illustration alone would be sufficiently clear to understand what the respondent was trying to describe. However, in case it was not, and in order to let the student justify his or her explanation, there was a space available for a written justification. The students were instructed to complete both the illustrative and written portions of the questionnaire.

The light question differed from the other two questions in one fundamental way. Besides the obvious content differences, the question concerning light was
given to the students using three slightly varying forms. It must be stressed that each student was only given, and only observed, one particular version of the questionnaire. Ultimately, roughly one third of the participants completed each of the three different versions of the questionnaire.

The different light questionnaires varied only in the way the glass was pictorially represented, not in what was asked of the student (see Figure 3.2). In the first version the glass was represented as a rectangular box with nothing inside. In the second version the glass was also represented as a rectangular box, however, this time there were “x” marks inside ostensibly representing molecules. In the third and final version the “x” marks are also represented, but in this version there was no rectangular box drawn.
This approach was employed for two reasons. The first was that research has shown student answers to conceptual questions can be influenced by subtle cues in the word phrasing or illustration of the apparatus (Engel, 1983; McCullough, 2004; Mildenhall, 2001). By making the slightly different versions of the questionnaire available, it was possible that some differences in performance related to differing versions would be noticed during analysis. The second reason this method was being utilized was that during preliminary testing in the fall of 2009
there were some interesting differences observed when students were presented with these different illustrations in the same problem context.

**Light background.** It is important to understand the physical concepts the students were exposed to relating to light prior to the dissemination of this questionnaire. The material covering electromagnetic radiation began approximately six weeks into the semester with the introduction to wave theory (see Appendix 7). Waves were grossly defined as “a disturbance that propagates through a material medium or space.” It was stressed that waves transfer energy without the bulk transfer of matter. The fundamental characteristics used in wave description were delineated as amplitude (A), phase (Φ), wavelength (λ), frequency (f), period (T), and velocity (v). The basic equations related to these characteristics are:

\[
T = \frac{1}{f} \quad \text{(Eq. 3.4)}
\]

\[
f = \frac{1}{T} \quad \text{(Eq. 3.5)}
\]

\[
v = \frac{\text{distance}}{\text{time}} = \frac{\lambda}{T} = f*\lambda \quad \text{(Eq. 3.6)}
\]

Three fundamental wave properties relating to electromagnetic waves were explained to the students during
the lecture and demonstrated during laboratory sessions. The first of these was the law of reflection. The law of reflection was verbally defined as “the angle of incidence is equal to the angle of reflection”, or in equation form:

$$\theta_i = \theta_r$$  \hspace{1cm} (Eq. 3.7)

A typical illustration of the law of reflection used during the course is shown in Figure 3.3.

![Typical diagram of the law of reflection.](image)

The next wave property discussed in class was diffraction. Diffraction was described as “the spreading of a wave around a barrier or through an opening.” The students were not exposed to the intricate mathematics of
diffraction; the only equation used to some extent was the one describing Young’s double slit experiment.

$$\lambda = \frac{(x \cdot d)}{L} \quad \text{(Eq. 3.8)}$$

In this equation, \(x\) is the distance between bright bands on the screen, \(d\) is the distance between slits, and \(L\) is the distance from the slits to the screen. During the discussion of diffraction some mention was made of Huygens – Fresnel principle and the construction of diffraction gratings.

The third wave property discussed during the class lecture period was refraction. The definition of refraction was given as “the change of direction of a ray of light as it passes obliquely from one medium into another of different transmission speed.” The students were exposed to the basic governing equation of refraction known as Snell’s law:

$$n = \frac{c}{v} \quad \text{(Eq. 3.9)}$$

$$n_1 \sin \theta_2 = n_2 \sin \theta_2 \quad \text{(Eq. 3.10)}$$

In this relationship, \(c\) is equal to the speed of light in a vacuum, \(v\) is the speed of light in the substance of
interest, and the ratio of these two quantities, known as $n$, is called the index of refraction.

A typical illustration used in class to demonstrate Snell’s law of refraction is demonstrated in Figure 3.4.

![Snell's Law](image)

**Figure 3.4.** Typical classroom representation of Snell's Law of refraction.

At this point the classroom lectures began to rather extensively cover mirrors and thin lenses (see Appendix 7). The coverage of mirrors and lenses did not consist of a rigorous mathematical exploration, but more of a qualitative analysis. The students learned to predict the nature of an image given the object’s distance to a certain type of mirror or thin lens. The students learned the two basic types of lenses and mirrors, converging and
diverging. The only equations used in this section of the course were equations for magnification and focal length.

\[ \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \]  
\[ \text{Eq. 3.11} \]

\[ \frac{d_i}{d_o} = \frac{s_i}{s_o} \]  
\[ \text{Eq. 3.12} \]

In the two equations, \( f \) is the focal length of the lens or thin mirror, \( d_o \) is the distance from the object to the thin lens or mirror, \( d_i \) is the distance from the mirror or lens to the image, \( s_i \) is the size of the image, and \( s_o \) is the size of the object.

The next section covered in the course relating to electromagnetic radiation was the nature of color. It was clearly stated in lecture that when light reaches a boundary between two media some of its energy is reflected, some of it is transmitted, and some of it is absorbed. Additionally, it was stated that the amount of light which falls into each of these three categories is dependent upon the frequencies of light, the angle at which the light reaches the boundary, and the nature of the two media. The students were then introduced to three levels of classification of materials based upon their optical properties (see Table 3.1).
Table 3.1

Light Properties of Material Objects.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transparent</td>
<td>Readily transmits light.</td>
</tr>
<tr>
<td>Translucent</td>
<td>Transmits, buts diffuses light.</td>
</tr>
<tr>
<td>Opaque</td>
<td>Transmits no light.</td>
</tr>
</tbody>
</table>

Subsequently, the nature of the relationship between observed color and wavelength was more thoroughly explained. It was shown that the spectrum of colors represented electromagnetic waves of wavelength approximately 400 nanometers to 760 nanometers. A typical slide from the class presentation on the wavelength nature of color is shown in Figure 3.5.
After discussing the wavelength nature of color, the students were exposed to some basic color theory. The students were told that the primary colors of white light are red, green, and blue. It was shown through multiple examples in lecture and laboratory that these primary colors can be mixed in various ways to create other observed colors. During these discussions students also became familiar with the idea that transparent objects are colored by the light that they transmit and opaque objects are colored by the light they reflect.

At this point it is very important to note what the students were not told. At no time during the class discussions on the nature of light and of light/matter
interactions were students given a conceptual model of what was occurring on the atomic scale. Students were made aware of what would occur on a macro scale (i.e. reflection, transmission, absorption) in various situations; however the microscopic interactions were not covered. This fact is almost universally true in undergraduate level physics courses. The proper nature of these light and charged particle interactions are extremely complicated and the student must be exposed to quantum electrodynamics to truly explore them. There are however simpler models of these interactions that can help students understand why certain wavelengths of light interact differently than other wavelengths. The nature of the students’ explanations of these phenomena will be explored in Chapter 4.

This brief review summarizes all the important aspects of electromagnetic radiation covered in the Physics 101 course during the spring semester. It must also be noted that prior to covering electromagnetic radiation the students covered general waves, Newtonian mechanics, and kinematics. The intensity of the coverage of these areas was of a similar level to the coverage of electromagnetic
radiation. That is the material was presented more qualitatively than quantitatively.

**Current question.** The second question administered to the research participants was the question titled “*How do you picture electrical current in a simple circuit?*” The question sheet is reproduced exactly as it was presented to the participants in Appendix 4.

For this particular question the participants were asked to describe, both graphically and verbally, what they thought was occurring inside the conducting wire at varying locations and in different temporal circumstances. A drawing of a simple circuit was presented on the questionnaire sheet that consisted of a chemical battery (pictorially represented as a standard nine-volt or PP3 battery), a single-pole, single-throw switch (SPST), a light bulb (pictorially represented as a generic incandescent bulb) and connecting wire. In order to limit participant confusion based upon possible misunderstood visual representations, the most basic and traditional images were chosen to represent each circuit element (McCullough, 2004).
Each participant was required to illustrate and verbally elucidate what they thought was occurring inside the wire at three different points (labeled A, B, C on the diagram) in the circuit. First they were to explain what was happening inside the wire at the three different positions when the switch was in the open position (i.e. the circuit was not complete). In the next section of the questionnaire the students were instructed to explain what was occurring inside the wire at the three separate positions immediately after the switch is closed (i.e. immediately after the circuit was completed). In the third and final section of the questionnaire, the students were asked to explain what was occurring inside the wire at the three separate positions after the switch has been closed for a “long time” (i.e. any supposed transients have dissipated).

A review of the participants’ academic exposure to the physical theories behind both the current question and the resistor question is presented in detail at the end of the following section.

**Resistor question.** The third question administered to the research participants was the question titled “How do
you picture electrical current in a resistor?” The question is reproduced exactly as it was presented to the participants in Appendix 5.

For this particular question the participants were asked to describe, both graphically and verbally, what was occurring inside a resistor connected to a simple circuit. The circuit was depicted schematically on the questionnaire and consisted of a resistor (represented by a drawing of a typical carbon resistor), a chemical battery (represented by a drawing of a PP3 battery, though nominally rated at ten volts), and connecting conducting wire. As in the circuit question the pictorial representations were purposively kept as simple as possible in order to limit confusion and thus increase the usable response rate.

The participants were asked to answer three separate, though intimately connected questions. For the first questions the participants were to both verbally explain and pictorially represent what was physically occurring inside a resistor of one ohm connected to a ten volt battery. In the second part the participants were to both verbally explain and pictorially represent what was physically occurring inside a resistor of two ohms that was
connected to a ten volt battery. In the third and final part the participants were asked to both verbally explain and pictorially represent what was physically occurring inside a resistor of ten ohms that was connected to a ten volt battery.

Current/resistor background. Immediately following the section of the course dealing with electromagnetic radiation, the lecture material moved on to electricity and magnetism. This portion of the course began in the eleventh week (see Appendix 7) of the semester and continued until the completion of the course (fifteenth week).

This segment of the Physics 101 course began with an introduction to charge on a subatomic scale. The nature of charge as it relates to protons, neutrons, and electrons was discussed. Students were told that charge occurs only in whole number integers of these basic charge carriers (i.e. no discussion of fractional charge carriers). During this time there was some discussion of the periodic table and how it relates to atomic construction. Isotopes and ions were explained thoroughly, though radioactivity was only briefly mentioned.
The nature of conductivity in materials was discussed multiple times. The students learned to classify materials into two broad categories, insulators and conductors. This dichotomous separation was used to describe why certain materials would become statically charged while others would not. Semiconductors were not discussed during this course. The basic law of electrostatics was presented to the students as “Like charges repel; unlike charges attract.” A typical slide used during the course to stress the basic law of electrostatics is shown in Figure 3.6.

Students were taught how to charge objects by either conduction or induction. It was verbally described and pictorially shown how both charge methods work. During
these discussions it was mentioned that electrons were free to move between objects while protons were not.

Though not used to calculate solutions to problems, the students were presented with Coulomb’s law in the form:

\[ F = k \frac{q_1 q_2}{d^2} \]  

(Eq. 3.13)

In this well known equation, \( F \) is the force exerted on the charged particles, \( k \) is the universal electrostatic constant, \( q_1 \) and \( q_2 \) are the respective charges on objects (1) and (2), and \( d \) is the distance between the two objects. The primary goal of introducing Coulomb’s force law to the students was with the intention that they learn the direct relationship between charge and force and the inverse squared relation between force and distance.

The next model introduced in the course was the concept of an electric field. This was initiated by the students drawing electric field lines around various charge configurations; eventually the basic field equation was introduced.

\[ E = \frac{F}{Q} \]  

(Eq. 3.14)
In this equation, \( E \) is equal to the electric field strength, \( F \) is the electric force experienced by the object, and \( Q \) is the charge of interest. A typical illustration used in class is shown in Figure 3.7.

![Figure 3.7. Typical example of electric field lines.](image)

The next topic covered was the idea of electric potential difference. This was the formal introduction for the students to voltage, through the equation:

\[
V = \frac{W}{Q} \tag{Eq. 3.15}
\]

\( V \) represents the electric potential differences in volts, \( W \) is equal to work, and \( Q \) is equal to amount of charge. The verbal definition for volt supplied to the students was, “One volt is the electric potential...”
difference between two points when one joule of work is done in moving one coulomb of charge between the points.”

After voltage was defined for the students the lecture moved on to chemical cells. The students were able to create simple chemical cells using various materials and measure the resultant voltage with a digital voltmeter. Chemical cells were simply defined as entities that turn chemical energy into electrical energy. Students were shown how a battery is merely a combination of multiple chemical cells. The only mathematical component to this section was finding total voltages when multiple chemical cells were combined into an assortment of series, parallel, and combination configurations.

The topic of electric current was also covered during this portion of the course. Electric current was defined to the students as “the flow of charged particles; can be positive or negative, but usually negative (electrons) through a conducting metal.” In order to properly discuss current it was necessary to introduce the SI unit for current, the ampere. The ampere was defined by this statement: “One ampere is the flow of one coulomb of charge per second.” When I is current in amperes, Q is charge in
coulombs, and t is time in seconds, the equivalent statement in equation form is:

\[ I = \frac{Q}{t} \quad \text{(Eq. 3.16)} \]

After the study of current was completed the course moved on to power. The students were told that the SI unit for power is watts and the following relationship was given:

\[ P = V \times I \quad \text{(Eq. 3.17)} \]

In this equation, P is power in watts, V is electric potential difference in volts, and I is current in amperes.

The concept of resistance was covered rather extensively during the Physics 101 course. As in most physics textbooks, the first topic covered when discussing electrical resistance was Ohm’s law. Ohm’s law simply relates voltage V (volts), current I (amperes) and resistance R (Ohms) through the following simple equation:

\[ V = I \times R \quad \text{(Eq. 3.18)} \]

It is important to understand what the students were told concerning resistance since the resistance questionnaire it highly dependent upon this. The students
were told that three characteristics affect the resistance of an object. The first was the length of the conducting path. With everything else being equal, the longer the resistor the more total resistance it would have. The second was the cross sectional area of the resistor. Generally the greater the cross sectional area, the lower the resistance. For instance, a thicker gauge wire has less resistance than an otherwise equivalent thinner gauge wire. The last characteristic given was resistivity, which is a function of the material comprising the resistor. The students were told that there is a direct relationship between resistivity and resistance, the greater the resistivity of the object the greater its resistance. It was never explicitly explained to the student what causes differing levels of resistivity in materials. The introduction of resistivity included one new equation:

\[ R = \rho \frac{l}{A} \]  

(Eq. 3.19)

In this formula, \( R \) is the total resistance, \( \rho \) is the resistivity, \( l \) is the length, and \( A \) is the cross sectional area. After obtaining some understanding of resistors, students were given instruction on how to calculate the total resistance of different configurations of resistors.
The last section of circuit analysis dealt with Kirchhoff’s rules for circuits. The first Kirchhoff rule given was the loop rule. The definition given during the course for the loop rule was “The sum of the potential differences around any closed circuit loop is zero.” The second Kirchhoff rule is known as the junction rule. The definition provided to the students for the junction rule was, “The sum of the currents into any current junction is zero.” With Ohm’s law and the two Kirchhoff rules, the students were able to analyze simple direct current circuits.

The last section of the course covered magnetism. This began with defining three different types of magnetism (see Table 3.2).

**Table 3.2**

Types of Magnetism.

<table>
<thead>
<tr>
<th>Type of Magnetism</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferromagnetic</td>
<td>Strongly attracted to magnets.</td>
</tr>
<tr>
<td>Paramagnetic</td>
<td>Slightly attracted by strong magnets.</td>
</tr>
<tr>
<td>Diamagnetic</td>
<td>Slightly repelled by strong magnets.</td>
</tr>
</tbody>
</table>

-145-
It was explained to the students that magnetism is the result of electrical charges in motion. The basic law of magnetism was presented to the students as “Like poles repel; unlike poles attract.” The relationship between electricity and magnetism was demonstrated by using a simple electric motor. The section on magnetism was primarily qualitative with little to no mathematical rigor employed.

**Methodology summary.** This research project relied on the study of 135 pre-service education students. These students were queried on three questions relating to electromagnetism. The results of these three questions were thoroughly analyzed in an attempt to discern the nature of the students’ explanations. After the explanations were categorized in various ways they were checked for any relation to available academic data. It was hoped that through this analysis a better understanding of pre-service teachers’ conceptual views on electromagnetism was obtained. The three research questions used in this project were each chosen for very specific reasons. The questions had to meet certain requirements in order to be chosen for use in this project. The purpose of the research project was to analyze student
conceptions of electromagnetism, more specifically, student conceptions concerning the atomic level interactions in electromagnetic phenomenon. It was fundamental that the students be allowed to express what they thought without the constraints of a multiple choice answer system. Thus all the question sheets were of the open-ended variety; with the student explaining their answers in both written and graphical terms. Lastly, because these question sheets were distributed during class lecture time it was important that they not be too time consuming, accordingly each question sheet was limited to one page and should have taken the students no more than 15 minutes to complete.

The first question distributed to the students pertained to electromagnetic radiation (i.e. light). In this question the students were asked to explain what would happen when certain frequencies of light struck various objects, both transparent and opaque. The students had received instruction concerning light and color theory. They however were not instructed on what “actually” occurs on an atomic scale during light/matter interactions. This question was chosen specifically because there has been very little research done on how students perceive
light/matter interactions and thus this question can add substantially to the literature.

The second question distributed to the students dealt with current electricity. In this question the students were asked to explain what they thought was occurring inside a wire connected to a complete electrical circuit during various circumstances. The students were shown a diagram with three different wire locations marked and were asked to describe what was occurring at these three points during three different time periods. Once again their explanations were both written and graphical. This question was chosen because research has shown that students have many misconceptions of current electricity. It is hoped by asking the question in this form (different locations on a circuit, different times relating to circuit closure) a better understanding of student confusion can be obtained.

The final question involved another electrical circuit, though this time it was connected to a resistor. The students were instructed to both write and draw what they thought was occurring inside the resistor when it was connected to a chemical battery. They performed this
analysis for three different resistors. This question was chosen because as in the case of the light question there has been little to no research in how students perceive resistors conceptually. Additionally, it is hoped that by better understanding student perceptions of resistance we can better comprehend their overall theoretical picture of electricity.

Though there were countless different questions that could have been chosen to explore student conceptions of electromagnetism, it was believed that these three particular questions would shed some light on how students process the data they acquire during an introductory physics course.
Chapter 4: Results and Discussion

Introduction to Data Analysis

There were countless ways in which the data generated during this research project could have been analyzed. Due to the intensive labor time needed to perform an analysis on such a large data set, only a few different analysis methods could feasibly be employed. The methods selected to be incorporated in this report were the methods thought to provide the most insight into student conceptions of electromagnetism.

An important part of any analysis is the person or people performing the analysis itself. All of the different analyses performed for this research project were performed by the principle investigator. The principle investigator performed the data acquisition personally as well. Most of the analytical methods used for this project required the researcher to make subjective judgments concerning the nature of the student responses to the questionnaires. An advantage of using only one analyst was the relative high level of internal consistency; of course
the disadvantage of only one researcher was the limited resources that were available to analyze data, resulting in a project of smaller scope.

**Epistemological Representation**

The first step in the analysis of the questionnaires in terms of epistemological representation was to classify each response according to the protocol set forth by Driver and her coauthors. This means that each answer on the questionnaire sheets (three per questionnaire), was classified into one of the following categories, phenomenon-based reasoning, relation-based reasoning, or model-based reasoning. This approach implies that a particular student may reason at different levels within the same questionnaire sheet.

The three levels of epistemological representation are detailed in Table 2.1. The highest level of epistemological representation presented by Driver and her coauthors is called model-based reasoning. When using model-based reasoning a student would exhibit certain characteristics, such as a clear distinction between description and explanation, entertaining multiple possible models, and acknowledging that the relationship between
theoretical knowledge and natural phenomenon is problematic.

For instance, a model-based response to the light question would have covered several points. A model-based theory would have had to postulate the existence of a microscopic entity within the glass affecting the incident light waves. Presumably this would have been molecules, atoms, or electrons. The model would have had to produce a frequency dependent relation between the incident light and the microscopic entities to explain why different colors interact differently with the medium. Lastly the student should have acknowledged that multiple models are possible explanations for the depicted phenomenon. Interestingly, none of the student responses for any of the question sheets attained this level of reasoning.

The potential reasons why none of the student responses fell into the model-based category are manifold. One possible explanation was that the students did not fully understand the intention of the question and therefore failed to answer in the most thorough way possible. While always a possibility, it was hoped that the countermeasures enacted were sufficient to reduce this
problem to a statistically small sample of students. As previously stated, the primary measures used to prevent student confusion were a thorough verbal and written explanation as to what was expected in terms of correctly addressing the question.

It was postulated that the foremost explanation of why the students did not reason on a model-based level was a poor understanding of the nature of scientific theories. Educational research has consistently shown that students have a limited perception of the nature of science and the characteristics of scientific theory (Osbourne et al., 2003; Dagher et al., 2004; Carey et al., 1989). In order to properly reason at a model-based level one must have some fundamental understanding of the nature of scientific theories. The students in the Physics 101 course were not on track for a scientific career and generally had a low level of exposure to the sciences when compared to students in other academic programs. The explanations submitted for the questionnaires generally failed to meet the standards proposed by Driver and her coauthors for model-based reasoning most likely due to this fact.
As evidenced in the following examples, it seemed that many times the students’ answers were not logically consistent. It is of course absolutely fundamental that scientific theories demonstrated logical consistency. For instance in Figure 4.1 the student demonstrates inconsistency in the application of deduction.

In case 1 the student stated, “When light goes through glass it slows down since it is transparent, it has no effect on the colors.” This implied that the changing of the speed of light had no effect on the perception of color, and that transparent glass changes the speed of red, green and blue light. However, in case 2 the student stated that red and green light would transmit through blue glass (as clearly depicted in the drawing), albeit with a changed speed. The student then stated that “the blue remains constant,” meaning that the speed of blue light remained constant. This logic predicted that the three colors would penetrate the blue glass as in case 1 with the only noted difference in the two cases being the unchanged speed of blue light. If changing speed had no effect on color (as presumed in case 1), then the two cases were fundamentally the same and there was no rationalization for the difference in color of the two glasses.
The student respondent also committed a logical error in case 3. In the explanation of case 3 the student stated, "The red and green are absorbed but the blue is reflected." This explanation was not consistent with the pictorial representation in which it was very apparent that the red and green light rays were in fact transmitted through the piece of opaque wood.
Light question. In Table 4.1 it was noted that the majority of the Physics 101 students answered the light question in a manner that corresponded to Driver’s lowest level of epistemological representation, namely the
phenomenon-based level. Responses in which the student failed to distinguish between a description of the phenomenon and an explanation were classified as phenomenon-based. Typically for this question students would state that “light transmits” through transparent glass. This type of response did not reach the level of relation-based or model-based reasoning. In Figure 4.2 a typical example of a phenomenon-based answer to the light question was demonstrated.
In Figure 4.2 the student had not really explained more than was given in the initial problem. For instance, in case 3 the student stated, “No light can get through opaque wood.” This did not provide any insight as to what
physically happened in the interaction between light and wood.

Figure 4.3 was another example of a student using phenomenon-based representation. Here we can see that the student had not given any new information. For example, in case 2 the question was to explain the interaction between light and blue glass. The student simply stated, “You see the color blue because the glass is blue.” This tautology does not help to understand why the glass interacts differently with blue light than it does with either red or green light. In case 3 the student respondent again failed to elucidate what had occurred between the blue painted wood and the three light rays to produce the sensation of blue when viewing the wood. The respondent simply stated, “No color (has?) gone through because it is wood.”
A significant portion of student responses fell into the relation-based reasoning category (see Table 4.1). A typical example of a student response that was classified into the relation-based reasoning category was shown in Figure 4.3.
Figure 4.4. This particular example was interesting because even though the student was incorrect in his or her assumptions, the reasoning was still relation-based. In this example, the student was making the assumption that the color of the glass affects how the different wavelengths of light interact with the medium. This is of course reversed because in fact how the light rays interact with the medium determines the color and not vice versa.

Though incorrect, the student used the observable features of the medium (i.e. its color) to explain or predict what would happen when different color light rays interact. The relationship the student devised to understand this phenomenon was that the only light rays allowed through a medium were those that have the same color the medium already possessed. We see in case 1 that the medium was colorless, so in this special case any color could pass through the medium. In case 2 the glass was blue, this implied that only the blue light ray would be able to pass through the glass and the other colors would be negated. The important idea here was that the student was relating the transmission of light to an observable phenomenon of the medium, namely its color.
Current question. Just as in the case of the light question, none of the student responses to the current question were of sufficient quality or breadth to attain the status of model-based reasoning (see Table 4.1). A
representative example of phenomenon-based reasoning for this question was Figure 4.5. Here we see that the student was merely stating information that was either in the problem description or exceedingly obvious. In case 1 the student stated for the three locations, “The switch is open so there is some sort of activity”, “There is nothing happening because the switch is off,” and “There is little activity because it had to pass through the switch.” These types of responses were typical of phenomenon-based reasoning.
Driver stated that a primary characteristic of phenomenon-based reasoning was no clear distinction between the phenomenon and the explanation. We can see this explicitly in Figure 4.6. When a circuit is open it is
generally understood that there is no current flowing through the wires. Students should be aware of this both from their class lectures and through everyday experience of plugging in and using electrical appliances. However, we can see that in case 1, when the switch was open, the student stated, "There is no current." Here the student was stating the obvious and not addressing the question. The drawing was of no help either, because the student chose to represent a no current situation as nothing existing in the wire. In case 2 the student was to explain what happens in the wire immediately after the switch had been closed (i.e. switched on). The students were expected to know that normally electricity flows when electrical appliances are switched on. For this case the student stated, "It is receiving a jolt of electricity." As in case 1 the student was failing to distinguish between phenomenon and explanation. This type of response was typical of the phenomenon-based explanations encountered for the current question.
Though most of the responses were phenomenon-based, there were a significant number of relation-based answers as well. In order to be classified as relation-based the response did not necessarily have to be correct, it only
needed to demonstrate attributes of relation-based reasoning, such as distinction between description and explanation, linear causal sequence, and correlation between variables. In Figure 4.7 the student used a more relation-based approach to the question. The student believed that current constantly flows out of the battery through whatever channels were available. This logic was then applied to the different scenarios and locations. Accordingly, in case 1 (location C) the student stated, “The battery is giving off a charge but all the charge is staying still.” In case 1 (location B) the student stated, “Same thing is going on here because the switch is off so the electricity is not coming in.” Here the student followed his/her logic to its ultimate conclusion; electricity left the battery and flowed to the switch where it was stopped from further travel. This approach was not correct, but the student was applying a methodology logically.
Figure 4.7. Example of relation-based representation.

In Figure 4.8 the student also exhibited relation-based reasoning, though using a slightly different approach. Here the student supposed a view of current electricity in which negative charge continually flowed
from the negative battery terminal and positive charge continually flowed from the positive terminal. This approach was the basis for a common misconception to be analyzed in the subsequent section. In case 1 the open switch effectively divided the circuit into two sections, one connected to the positive terminal and the other to the negative terminal. It can be observed that the student correctly applied this logic, stating in case 1, “A: Positive charge is moving from the battery to the light,” “B: There is no charge,” and “C: A negative charge is moving from the battery to the switch.” This explanation was fully consistent with a theoretical viewpoint of positive charge continually leaving the positive terminal and negative charge continually leaving the negative terminal.
Resistor question. Just as in the light and current questions, none of the student responses for the resistor question were of sufficient quality or breadth to attain the status of model-based reasoning (see Table 4.1).
A representative example of phenomenon-based reasoning for this question was Figure 4.9. This particular questionnaire was classified as phenomenon-based reasoning because the student was not providing an explanation for what was occurring within the resistors and why they thought this might be occurring. For each of the three cases the student illustrated discrete charges within the wires. However, inside the resistor the student only drew a jagged line resembling a triangle wave and wrote the word “resistance.” These types of drawings did very little to explain the mechanisms of electrical resistance. For the three cases the student wrote, “1 Ohm: Not much resistance so current flow is constant(?)”, “2 Ohm: A little more resistance so flow is a little harder,” and “10 Ohm: A lot of resistance so the current flow is blocked.” The verbal descriptions also did not add pertinent information to the question at hand. The student stated that the resistance was different in each of the three cases. This was correct, but was listed very clearly in the problem description. The student also stated that the current flow became more difficult as the resistance increased. This was also true, but the student did not attempt an
explanation as to what factors within the resistor might contribute to the electrical resistance.

Figure 4.9. Example of phenomenon-based representation.

Figure 4.10 was another example of phenomenon-based representation. In this particular case the student
produced drawings of positive and negative charges with arrows ostensibly representing movement or forces. These drawings were interesting, but without an accompanying verbal description it was not possible to fully ascertain what the student was trying to express in the drawings. The written explanation fell short in this respect, specifically the student stated, “1 Ohm: Not much resistance is occurring inside the resistor because only 1 ohm is apparent;” “2 Ohms: 2 ohms makes the circuit have a little more resistance,” and “10 Ohms: A lot more resistance is in the circuit due to 10 ohms.” As in the previous case (Figure 7.1) the student merely restated information given in the problem description. Unfortunately, these explanations did not allow proper interpretation of the drawings and therefore relegated this questionnaire to the phenomenon-based category.
For the resistor question there were slightly more responses in the relation-based category than in the phenomenon-based category. In order to be classified as relation-based the response does not necessarily have to be
correct, it only needed to demonstrate attributes of relation-based reasoning such as distinction between description and explanation, linear causal sequence, and correlation between variables.

Figure 4.11 was an example of a response that was categorized as relation-based. This response demonstrated that the student postulated a relationship between the resistance of a resistor and the quantity of charged objects within that resistor. For the 1 ohm case the student stated, “The 1 ohm has the least resistance and therefore will have less going on inside of the resistor but the outside current will be constant.” The accompanying picture showed one positive and one negative charge inside the resistor. For the 2 ohm case the student stated, “The 2 ohm circuit will have slightly more occurring inside the resistor but all have the same flow on the outside.” In the picture for this case the student had drawn six positive and negative charges inside the resistor. In the 10 ohm case the student stated, “The 10 ohms has the most resistance and therefore more going on inside with constant outside.” The associated diagram for this case consisted of nine positive and negative charges inside the resistor.
From these diagrams and written explanations the approach the student was using to answer the questions could be ascertained. Apparently, the student believed that resistors were entities containing charged objects. The larger the rated resistance of the resistor (in ohms), the more charged objects the resistor contained. There was no linear relationship between the number of charges and the resistance in ohms, just a direct relationship of unknown form. These charged objects act as a sort of barrier to incoming charge, this barrier effect was recorded as resistance. Interestingly, the student predicted that the changing number of charged objects inside the resistor, or the resistance, would not have any effect on the current flow. This was incorrect; in fact for this simple circuit any changes in the resistance would have dramatic effects on the amount of current flow. Though this particular approach to explaining resistance was not correct, the student did create a primitive relation between charges and resistance and apply it somewhat consistently over the three cases and thus this response was considered relation-based.
Another example of relation-based representation was presented in Figure 4.12. Once again the relation used by this student was incorrect, but this was immaterial to Driver’s classification scheme. This student believed that
resistors functioned as a sort of speed bump in the electrical circuit. In other words, the charge carriers move very rapidly around the circuit until they enter the resistor. At this time they slow drastically and remain slow throughout their passage of the resistor. Upon exiting the resistor they again retain their former speed. The resistance rating (in ohms) was proportional to the speed of the charge carriers in the resistor, the higher the resistance the lower the translational speed. As a corollary the student stated that the speed of the charge carriers in the wire was proportional to the resistance of the resistor. However, in this case there was an inverse relationship. This was clearly seen in the students statements which were as follows, “1 Ohm: The atoms slow through the resistor however the overall speed is the slowest,” “2 Ohm: As the atoms move through the resistors they move more slowly than in the wire. The 2 Ohm overall speed is in the middle of the 1 Ohm and 10 Ohm,” and “10 Ohm: The atoms still slow through the resistor, however the overall speed is much faster than the 1 and 2 Ohm.” Once again, the student was incorrect in their logic but did incorporate a rudimentary relationship between resistance and translational speed of charge carriers.
The fact that the majority of Physics 101 students used phenomenon-based representation was not entirely surprising. Through interacting with these students over the past few years the author has witnessed firsthand their
difficulties with the nature of scientific thinking and theories. It must however be remembered that this classification does not represent the general nature of student thinking, only the classification of their performance for this particular problem.

Table 4.1

Epistemological Representation Frequencies Including Percent of Students with Phenomenon-based reasoning.

<table>
<thead>
<tr>
<th>Question</th>
<th>Phenomenon-based</th>
<th>Relation-based</th>
<th>Percentage Phenomenon-based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Question</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case 1</td>
<td>86</td>
<td>44</td>
<td>66</td>
</tr>
<tr>
<td>Case 2</td>
<td>107</td>
<td>23</td>
<td>82</td>
</tr>
<tr>
<td>Case 3</td>
<td>97</td>
<td>33</td>
<td>75</td>
</tr>
<tr>
<td>Current Question</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case 1</td>
<td>84</td>
<td>45</td>
<td>65</td>
</tr>
<tr>
<td>Case 2</td>
<td>82</td>
<td>48</td>
<td>63</td>
</tr>
<tr>
<td>Case 3</td>
<td>88</td>
<td>42</td>
<td>68</td>
</tr>
<tr>
<td>Resistor Question</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case 1</td>
<td>60</td>
<td>65</td>
<td>48</td>
</tr>
<tr>
<td>Case 2</td>
<td>62</td>
<td>63</td>
<td>50</td>
</tr>
<tr>
<td>Case 3</td>
<td>62</td>
<td>63</td>
<td>50</td>
</tr>
</tbody>
</table>
As can be observed in Table 4.1 the majority of responses for the light question were categorized as phenomenon-based. This percentage phenomenon based varied somewhat between the three different cases and was highest for the transparent blue glass example (i.e. case 2). The lowest percentage of student responses classified as phenomenon-based occurred for case 1, or the transparent clear glass example.

As in the light question, the majority of student responses for the current question were phenomenon-based (roughly 65% total). There was very little variance between the three cases presented on each questionnaire, with case 3 having the most phenomenon-based results and case 2 have the least.

Unlike both the light and the current questions, the percentage of students in the phenomenon-based category for the resistor question comprised less than half the total respondents. The number of respondents in the phenomenon-based category was very consistent for the three different cases. Cases 2 and 3 had an identical number of phenomenon-based responses while case 1 only had two less, thus the variance in the numbers appears to be very small.
Interestingly, it appears there may be an association between the difficulty of the question and the type of epistemological representation the student demonstrates. The resistor question was regarded as the most difficult because the students were less familiar with the mechanics of electrical resistance than either of the other two phenomena. The resistor question had the lowest percentage of phenomenon-based representations, averaging about fifty percent of respondents.

In her book Driver and her coauthors stated that students may perform work in any of the three categories depending upon a number of factors. That conjecture was borne out during this research project. Of the 130 student responses completed for the light question, only 85 of the students answered all three questions using the same level of epistemological representation. This left 45 students (roughly one-third of the students) answering the three questions using different levels of epistemological representation. Similar results were found for the other two questions further validating Driver’s claims regarding student variability in epistemological representation.
Driver and her coauthors also stated that there was no necessary correlation between academic performance and epistemological representation. Table 4.2 presents the epistemological representation data along with the average final grade per category. There was obviously not a linear relationship between epistemological representation and final course grade with regards to the light question. The situation was slightly different for the other two questions. For these questions the categories of one and two phenomenon-based responses can be dispensed with because of the small numbers of students. If only the zero and three categories are analyzed it appears that the mean final grade increases with number of phenomenon based results. When the standard statistical analysis was performed it was found that only for the resistor question was the difference significant.
<table>
<thead>
<tr>
<th>Number of Phenomenon-based Responses</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Z</th>
<th>p &lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Question</td>
<td>80%</td>
<td>83%</td>
<td>81%</td>
<td>77%</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>n</td>
<td>73</td>
<td>26</td>
<td>19</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current Question</td>
<td>79%a</td>
<td>81%</td>
<td>88%</td>
<td>82%b</td>
<td>1.34</td>
<td>ns</td>
</tr>
<tr>
<td>n</td>
<td>79</td>
<td>7</td>
<td>4</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistor Question</td>
<td>79%a</td>
<td>83%</td>
<td>58%</td>
<td>84%b</td>
<td>2.77</td>
<td>0.05</td>
</tr>
<tr>
<td>n</td>
<td>59</td>
<td>2</td>
<td>3</td>
<td>61</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note. Current/Resistor question analysis only performed for a and b.*

**Misconceptions Represented**

A second analysis that can be performed on the data set procured for this research assignment was an analysis of misconceptions. The most common misconceptions identified in previous research were used to create the initial categories to classify the student responses. Additional categories were created if a sufficient number of students showed a common misconception. Previous
research on electromagnetic radiation showed that students tended to have some misconceptions that appeared regardless of the researcher or the participant pool.

**Light question.** A very common misconception observed in previous studies was the idea that color was an inherent property of an object such as mass or density are (Apelman, 1984). This misconception was recorded in the light questionnaire on nineteen occasions, or roughly 15% of the responses (see Table 4.3).

In the following examples we can see a sampling of students demonstrating this rather common misconception. In Figure 4.13 case 2 the student stated, "Since the glass is blue, red and green light will be absorbed and blue will be reflected." Here the student had committed a fundamental mistake and confused cause with effect. The idea that the glass "being blue" would cause light to interact differently shows that the student was relying on a faulty concept of light and color.
In Figure 4.14 case 2 the student stated, “Only the blue light travels through blue. Red and green come out dark or black, because they are primary colors and none mix for form blue.” Here again the student stated the primacy
of the color of the object in determining what wavelength of light would be transmitted. The second sentence also contained a misconception that will also be addressed in this report.

Figure 4.14. Example of nature of color misconception.
In Figure 4.15 case 2 the student stated, "Blue will be absorbed since the glass is blue + red + green will be transmitted." Here the student demonstrated the nature of color misconception in addition to multiple other problems. Even though blue light would not be appreciably absorbed as the student stated, the student continued to identify what happened to various wavelengths of light based on the concept of inherent object color.
In the final example for this section, Figure 4.16 case 2 the student stated, “Only a blue light can be seen on a blue glass, the other colors won’t appear & it will seem dark.” Once again the student was discussing the blue
glass independent of the blue light. In effect, the student was saying the color of the glass determined how light would interact, implying that color existed prior to the introduction of light.

Figure 4.16. Example of nature of color misconception.
Another misconception held by a minority of students concerned the nature of how people observe color. Since humans passively observe incoming light rays the color we perceive an object to be must result from light first interacting with the object, and then subsequently reaching our eyes. The misconception observed on this particular question was that certain students believe for an object to be a certain color then it must absorb that particular color of light. This is patently false because if the object absorbed a particular wavelength (i.e. color) of light, then there would be no way our eyes could receive that specific wavelength. In Figure 4.17 case 2 we can see a student clearly demonstrating this misconception. The student stated, “Red + green are reflected but blue is absorbed so you see blue.” In case 3 the student once again predicted that an observer would “see blue” because blue light was being absorbed by the wood.
In Figure 4.18 we again see this misconception in another student’s work. In case 2 the student stated, “The blue (light) will disappear/blend in with the glass. The red and green may turn dark.” Effectively the student was
saying that the transparent blue glass in case 2 would selectively absorb blue light.

Figure 4.18. Example of perception of color misconception.

Figure 4.19 was another demonstration of a student possessing the same misconception seen in Figures 4.17 and
4.18. In case 2 the student stated, “The red + green slow down + refract towards the normal. The blue light is absorbed in the blue glass.” Here the student again presupposed that in order for the glass to be seen as blue, it must absorb blue light.

Figure 4.19. Example of perception of color misconception.
Another interesting student misconception was observed during this research project and has not been noted in the reviewed literature. In order to understand this misconception one needs to understand what happens in case 2 (red, green, blue light incident upon transparent blue glass) to the red and green light. We have already stated that the blue light is primarily transmitted and thus the glass appears blue to our eyes. The red and green wavelengths of light are generally absorbed by the glass creating thermal excitation. Interestingly, a small number of students seemed to understand that the green and red wavelengths of light could not be cleanly transmitted or reflected in order for the glass to appear blue. However, instead of stating that the red and green wavelengths were absorbed, the students tended to believe that the red and green waves were transmitted or reflected, but had been made “dark” by the blue glass. Thus the red and green waves reach our eyes (either through reflection or transmission) but we do not perceive the color because they have been made dark.

In Figure 4.20 we can see a very typical example of this misconception from a student question sheet. In case 2 the student stated, “The red and green are made dark
while the blue stays the same.” By using the terminology “made dark” the student implied that the rays were still in existence only that their color attribute had been altered.
In Figure 4.21 the interesting concept of making colors dark again appeared. In case 2 the student stated, “Only the blue light travels through blue. Red and green come out dark or black, because they are primary colors and none mix to make blue.” Here the student was very specific, red and green came out dark or black. In other words during the transmission through the blue glass both the red and green light waves were somehow transformed into dark or black light waves. The student explicitly showed in the drawing accompanying case 2 that the red and green rays had transmitted through the blue glass only now they were labeled as “black.”
In Figure 4.22 the student again demonstrated the belief that the red and green wavelengths of light could be transformed into “dark” light. Specifically in case 2 the student stated, “The red and green are getting absorbed so
it comes out as dark when mixed with blue. The blue get transmitted so it is still blue.” The student included a cryptic mention of “mixed with blue,” however the general misconception was clear. There was a clear distinction between “dark” and nonexistent, so this was not a simple case of semantics. In case 3 the student clearly labeled the light rays as “none” while in case 2 the student labeled them as “dark.”
In Figure 4.23 we once again note the misconception that the red and green wavelengths are transformed into “dark” wavelengths. The major difference was that this student presented a reason why this change took place. The student stated, “When red, green, and blue light reach a
transparent blue glass you will only see the colors that have blue in them (magenta, cyan, blue) and the others will just appear dark.” The student’s reasoning for why certain colors turn dark while others transmit unchanged consisted of two misconceptions intermixed. The student believed that the color of the glass ultimately determined which colors or wavelengths would transform into dark. This misconception has already been discussed. The other misconception was that colors not containing an element or being a secondary hue of the color of the glass would be turned dark.
Figure 4.23. Example of color absorption misconception.

Table 4.3 presents the frequencies of student misconceptions related to their final course grades. It can be observed that even though differences in course performance were observed, none reached the level of
statistical significance so the null hypothesis was retained. All three misconceptions tested for occurred in about 14% of the participants.

Table 4.3
Comparison of Students With and Without Light Misconceptions on Final Course Grade.

<table>
<thead>
<tr>
<th>Misconceptions</th>
<th>Without</th>
<th>With</th>
<th>Z</th>
<th>p &lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color Absorption</td>
<td>80%</td>
<td>81%</td>
<td>0.49</td>
<td>ns</td>
</tr>
<tr>
<td>n</td>
<td>112</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nature of Color</td>
<td>81%</td>
<td>78%</td>
<td>0.79</td>
<td>ns</td>
</tr>
<tr>
<td>n</td>
<td>111</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perception of Color</td>
<td>81</td>
<td>83</td>
<td>0.96</td>
<td>ns</td>
</tr>
<tr>
<td>n</td>
<td>114</td>
<td>16</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Current question.** The misconception analysis was next performed on the current question. A common misconception observed in physics education research is the so called “clashing current” model of electricity (Kucukozer & Kocakulah, 2007; Pardhan & Bano, 2001). Pardhan and Bano showed that the clashing current misconception exists not only in students, but even in lower secondary science teachers. In the general form of the clashing current
misconception, the student believes that current leaves from both terminals of the battery and meets, or clashes, at the light bulb or other connected circuit element (see Figure 4.24). A slightly more specific example was when the student specified that positive current left the positive terminal of the battery and negative current left the negative terminal. This current then combined at the light bulb in order to produce light.
There are many examples of this misconception in the Physics 101 data set. Figure 4.25 was a representative example of student work demonstrating this misconception. In case 1 the student had drawn only positive charges for
position A, negative charges for position C, and a combination of positive and negative charges for position B. In the written explanation for case 1 the student stated, “A: Positive particles are at rest,” “B: Positive + negative charges are at rest around each other,” and “C: Negative particles are at rest.” The verbal description matched the diagrams perfectly and was indicative of the clashing current misconception. The verification of this misconception could be observed in case 2. Here the student stated, “A: Positive particles begin to move in direction of light bulb,” “B: Positive particles begin to move toward switch + negative begin to move toward light bulb,” and “C: Negative particles being to move toward switch.” The diagram and explanation for part 3 continued the application of the clashing current misconception.
Figure 4.25. Example of clashing current misconception.

Figure 4.26 was another example of a student that employed the clashing current misconception. This particular student also believed that negative charges would flow from the negative terminal of the battery while
positive charges would emanate from the positive terminal. For case 1 the student drew positive charges for picture A, nondescript dots for picture B, and negative charges for picture C. The verbal description for case 1 was as follows, “A: The protons are on the positive battery side because the light is off and the same repels,” “B: The neutrons are in this section since nothing is happening,” and “C: The electrons are being repelled on the negative battery side.” Once again the student believed that the charges left the separate battery terminals and would meet at the light bulb. Interestingly, the student believed that when the switch was open, neutrons would exist in the vicinity of the light bulb and this would explain why it was not glowing. After the switch had been closed, the student believed the protons and electrons switched places in the wire and combined to produce light in the bulb. Specifically the student stated for case 2, “A: Opposites attract so the electrons are on the positive side,” “B: Protons + electrons are evenly flowing, producing light,” and “C: Since opposites attract protons are on the negative side.” Here the student explained why the charges moved and how the light bulb lit up. The charges moved because they were attracted to the opposite terminal and the
recombination of charges caused the light bulb to glow. There were minor differences in how each student represented the clashing current misconception, but Figures 4.25 and 4.26 are typical.

Figure 4.26. Example of clashing current misconception.
A misconception that has been noted in previous literature was that some students picture electrical current as a wavy progression of energy (Kibble, 1999). Electrical current actually consists of discrete charged objects, generally electrons, propagating through space. Through their previous academic exposure, the students should have a conception of the idea of discrete charge carriers. In his 1999 article in *Physics Education*, Bob Kibble found that almost half (43%) of second year university students held the erroneous view of electrical current consisting of waves or sparks. In this research project it was found that approximately one-third of students held this misconception (see Table 4.4). In general, it was easy to discern this misconception based upon the pictorial representation provided by the students. Figure 4.27 was a typical example showing electrical current consisting of a wave-like structure. The student depicted the current as a sinusoidal wave running parallel to the length of the wire. It appeared the wavelength of the electricity was somewhat proportional to the amount of current. In case 2 location B the student stated, “Current is starting to go through point 'B’”, this is accompanied by a drawing of reduced wavelength. Thus the student
depicted electrical current as a wave-like progression with the amount of current being proportional to the wavelength.

<table>
<thead>
<tr>
<th>Name:</th>
</tr>
</thead>
<tbody>
<tr>
<td>How do you picture electrical current in a simple circuit?</td>
</tr>
<tr>
<td>You are aware that simple circuits contain electrical currents in certain situations. For each case below, draw and label a diagram that illustrates what is physically occurring inside the wire. In addition to your illustration, make a statement that explains why you think this is occurring inside the wire.</td>
</tr>
</tbody>
</table>

1. While the switch is open (off position):  
   - A: When the switch is open, electricity is passing from the battery to one side.  
   - B: The switch is not allowing the current to pass from A to B.  
   - C: The current is going from the battery and stopping |

2. Immediately after the switch is closed:  
   - A: Same as in the off position  
   - B: Current is starting to go through point  
   - C: Same as in the off position, but going through the switch |

3. 30 seconds after the switch is closed (on position):  
   - A: Same as in the off position.  
   - B: Current is passing through  
   - C: Same as immediately after |

![Figure 4.27. Example of wave current misconception.](image)

In Figure 4.28 another slightly different version of the wave current misconception was presented. Once again
the student used a wave-like form to represent electrical current. In this case however, the wave train ran perpendicular to the length of wire. Additionally, the wavelength appeared to represent a transient behavior of electrical current. In case 2, immediately after the switch was closed, the waves consisted of a relatively small wavelength. This contrasted with case 3 where the current had been flowing for some time. Here the student represented the waves as longer wavelength phenomenon. In the open switch circumstance, the student did not draw any lines within the wire.
These two cases are sufficient to demonstrate the wave current misconception. As stated earlier, roughly a third of the Physics 101 students chose to represent electrical current this way (see Table 4.4).
Another misconception observed relatively frequently in this data set concerned the fundamental nature of current flow. The accepted conception of current flow is as follows; when the circuit is completed by closing the switch, an electric field is set up in the conducting medium at nearly the speed of light, this field causes the loosely bounded electrons to move in one direction. The reality is slightly more intricate, with factors such as drift velocity, velocity factor of the material, and many others complicating the picture.

Many students verbally and pictorially described electrical current in a fundamentally different way. These students did not understand that current would begin to flow at each point in the circuit virtually simultaneously. These students would show current flowing in one portion of the circuit and not in others. This misconception was fairly common and has been uncovered in other research (Periago & Bohigas, 2005; Pardhan & Bano, 2001).

Figure 4.29 was an example of the current flow misconception. In case 1, where the switch was open, the student stated, “A: Electricity is running from the battery to the light bulb,” “B: Nothing is moving through the
wire,” and “C: Electricity is running from the battery to the switch.” In accordance with this misconception, the student stated that current was flowing in two parts of the circuit but not in the third. From this information it could also be deduced that the student had the clashing current misconception, since the current was flowing in opposite directions from opposite terminals. Only in case 3 did the student finally show the current flowing continuously through each part of the circuit.
Figure 4.29. Example of current flow misconception.

Figure 4.30 was another example of the current flow misconception. In case 1 the student stated, “A: There is (+) current moving,” “B: There is no current moving (it is stopped,”)” and “C: There is current moving.” Here again
the student believed that current was flowing from each battery terminal toward the light bulb. In case 3 the student stated, “A: + current moving,” “B: - current moving,” and “- current moving.” In this situation the student had finally stated that current was moving through each portion of the circuit. However, a new problem had arisen. The student had distinguished the current flow into positive and negative current. This brought up a problem of what happened when the positive current and negative current met, a problem not discussed in these questionnaires. These two examples are very typical of students with the current flow misconception. This type of response was also very similar to what previous researchers had found (Kucukozer & Kocakulah, 2007).
The current flow misconception was very common in this data set. Approximately 35% of the student respondents clearly demonstrated this misconception (see Table 4.4).
An interesting misconception observed in this data set was the so called “charged wire misconception.” When electrical current flows through a conducting wire it consists of multitudes of electrons drifting in one direction. Though these countless electrons are moving, they are doing so in a matrix of positive and negative charge. The net charge on a wire conducting electricity is zero. In contrast to this, some students believed the wire became positively or negatively charged when current passed through it.

Figure 4.31 was a typical example of this misconception as seen in the data set. In case 1 the student stated, “A: Wire is neutral because everything is off,” “B: Wire is neutral because switch is open,” and “C: Wire is neutral because switch is disconnected.” When the wire was disconnected the student correctly stated that the wire was neutral at all three locations. In case 2 the student stated, “A: Wire is positive because it is touching positive side of battery,” “B: Wire is neutral because it is in the middle of positive + negative sides of wire,” and “C: Wire is negative because it is touching negative side of battery.” Here the student fell into the misconception. It was naively postulated that the side of the wire
touching the positive terminal would become positively charged and the side of the wire touching the negative charge would become negative. The location of the wire equidistant from the poles of the battery would remain neutral. In case 3 the student retained the same answers as case 2.
In Figure 4.32 another student example of the charged wire misconception was presented. In case 1 the student stated, “A: When the switch is open the charge is positive,” “B: When the switch is open the charge between the light bulb and switch is negative, therefore the light
is not on,“ and “C: The charge between the battery and light bulb is negative, therefore no current is going to the light bulb.” Here the student believed the wire was divided between positive and negatively charged portions, however the division was not equal. The drawings provided by the student were consistent with these explanations. In this case the charge on the wire came not from a surplus of charge, but from an absence of opposing charge. The student continued this same theme throughout cases 2 and 3.
The prevalence of the charged wire misconception was relatively small; only 10 (roughly 8%) students clearly demonstrated it (see table 4.4). There were several additional questionnaires that possibly could have been
categorized as having the charged wire misconception, but the students provided very little or poor information.

The last misconception analyzed for the current question was called the “moving positive charge misconception.” As previously discussed, current in a wire is defined as charge passing a certain point per unit time, or more explicitly:

\[ I = \frac{Q}{t} \]  
(Eq. 4.1)

Where \( I \) is equal to current in amperes, \( Q \) is charge in coulombs, and \( t \) is time measured in seconds. This definition for current does not specify the charge carriers; they could be either positive or negative. However, the actual condition in metal conducting wires is that the charge carriers are negative, namely they are electrons. A significant number of students in the data set either verbally described, or pictorially represented moving positive charges.

An example of this was presented in Figure 4.33. In case 1 the student drew only positive charges in position A, only negative charges in position C, and both positive and negative charges in position B. The accompanying
statements were, “A: Protons come from the battery,” “B: Electrons + Protons are mixed,” and “Electrons coming from battery.” From these statements it was obvious the student believed positive charges, in the form of protons, were moving from the battery into the circuit. This theme of both positive and negative charges moving was continued throughout cases 2 and 3.
Figure 4.33. Example of moving positive charge misconception.

Figure 4.34 was another example of the moving positive charge misconception. In this case the student was less specific on where each type of charge came from or was flowing to. In case 1 the student stated, “A: Electrons +
protons are moving around because the battery [sic] is connected to the light,” “B: Electrons are still because switch is off disconnecting power,” and “C: Same as B.” The accompanying pictures were of little use in determining charge because the student only drew circles without denoting type of charge. From this verbal description, it was made clear that the student believed both protons and electrons were responsible for carrying charge in a metal conducting wire. In cases 2 and 3 the student continued to state that protons and electrons were moving. These two cases are representative of the typical response demonstrating the moving positive charge misconception. There were a few cases in which the student showed only positive charges moving without mentioning any movement of electrons, however these were less common.
The moving positive charge misconception was rather common in this data set. In total 54 students clearly demonstrated this misconception either through their
drawings or descriptions (see Table 4.4). This amounts to roughly 42% of the Physics 101 class.

<table>
<thead>
<tr>
<th>Misconceptions</th>
<th>Without</th>
<th>With</th>
<th>Z</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clashing Current</td>
<td>81%</td>
<td>83%</td>
<td>0.98</td>
<td>ns</td>
</tr>
<tr>
<td>n</td>
<td>105</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave Current</td>
<td>82%</td>
<td>78%</td>
<td>2.02</td>
<td>0.05</td>
</tr>
<tr>
<td>n</td>
<td>85</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current Flow</td>
<td>81%</td>
<td>80%</td>
<td>0.43</td>
<td>ns</td>
</tr>
<tr>
<td>n</td>
<td>84</td>
<td>46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charge Wire</td>
<td>80%</td>
<td>85%</td>
<td>1.96</td>
<td>0.05</td>
</tr>
<tr>
<td>n</td>
<td>120</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moving Positive Charge</td>
<td>80%</td>
<td>81%</td>
<td>0.74</td>
<td>ns</td>
</tr>
<tr>
<td>n</td>
<td>76</td>
<td>54</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When comparing misconceptions on the current question to final course grade in Table 4.4, two associations met the level of statistical significance. Students demonstrating the wave current misconception tended to perform worse in the course, as measured by final grade, than student without the misconception. On the other hand,
students with the charged wire misconception tended to score better on final course grade than their counterparts without the misconception.

**Resistor question.** The first misconception to be analyzed for the resistor question was the variable speed misconception. This particular misconception was observed in a significant number of student responses. This misconception was as follows. The students believe that the current (either discrete charge carriers or wave-like phenomenon) flows at a certain speed in the conducting wire. This speed changes drastically when the current enters the resistor. Here the students tend to think that the current slows dramatically. This was demonstrated quite clearly in Figure 4.35.

In the pictures drawn for the three different cases the student demonstrated a similar phenomenon. The electrical current arrived in the wire as a high frequency, small wavelength packet. Upon entering the resistor the wave was considerably stretched out. This was representative of the current slowing down as clearly explained in the written portion. For the three cases the student stated, “1 Ohm: The resistor is slowing down the
current,” “2 Ohm: The resistor is slowing down the current more than 1 Ohm” and “The resistor is slowing the current down the most.”

Figure 4.35. Example of variable speed misconception.
This exact misconception was not observed in any published research article. In fact, the literature on student conceptions of resistance on the microscopic scale was nonexistent. Though the exact misconception had not been observed it was believed to have been related to two misconceptions that are commonly seen in students. The first is the misconception that current is not conserved. Many students believe that current is created or used up as it flows through a circuit (Pardhan & Bano, 2001; Kucukozer & Kocakulah, 2007). However, the differential current flow rates predicted by a student with the variable speed misconception leads inevitably to conservation of current issues. The second misconception this may be related to was the attenuation model. This model is commonly exposed when students are asked which light bulb would be brightest in the simple series circuit of multiple bulbs. Students with the attenuation misconception will think that the bulbs will get decreasingly bright as current moves from one to the next instead of all being the same brightness.

In Figure 4.36 another version of the variable speed misconception was demonstrated. This student stated, “1 Ohm: The atoms slow through the resistor however the overall speed is the slowest,” “2 Ohm: As the atoms move
through the resistors they move more slowly than in the wire. The 2 Ohm overall speed is in the middle of 1 Ohm and 10 Ohm” and “10 Ohm: The atoms still slow through the resistor. However the overall speed is much faster than the 1 and 2 Ohm.” The drawings for this particular questionnaire did not add much information to the written description. Once again the student believed in a large speed differential between charge carriers in the wire and charge carriers in the resistor. The standard view is that the resistor will affect the total current flow through the circuit; however, this current will be constant over the entire circuit (i.e. through each circuit element and connecting wires). Obviously in addition to the variable speed misconception, this student also demonstrated several of the electromagnetic misconceptions observed in the current question.
A large portion of the Physics 101 students demonstrated the variable speed misconception. As Table 4.5 demonstrates roughly 38% (48 students) of the class were shown to have this misconception at some level. As
was the case with the misconception analysis generally, this number was most likely a lower limit due to difficulties in interpreting student data.

A second misconception, related to the first, was the variable current density misconception. As previously explained, the current in the circuit was the same at each point (within certain statistical permutations). Students holding this misconception tended to believe that the current in the resistor was significantly lower than the current in the wire. This brings up obvious conservation of charge issues. In Figure 4.37 the student stated, “1 Ohm: Since 1 Ohm has the least amount of resistance, the electrical current can flow pretty fast,” “2 Ohm: With 2 Ohms there is little resistance but there is some which makes the current flow not as easily” and “10 Ohm: With 10 Ohms there is a great amount of resistance which makes the electrical flow slower.” This student made it clear that the current would slow down when it passed through the resistor. This also implied a lower current rating unless the amount of charge carriers was accordingly increased which the student did not mention. The only viable conclusion was that the student believed the current flow inside the resistor to be lower than the rest of the
circuit. The supplied drawings reinforced this interpretation as the longer wavelength appeared to depict slower speeds.

![Diagram of electrical current in a resistor](image)

**Figure 4.37. Example of variable current density misconception.**
Figure 4.38 was another example of the variable current density misconception. The student drawings obviously showed a decreased charge carrier density within the resistor. This necessitated a lower current within the resistor unless the charge carriers were significantly speeded up upon entering the resistor. The potential solution was negated by the student statements which were as follows, “1 Ohm: Slowing down the electrons,” “2 Ohm: Electrons slow down more,” and “10 Ohm: Electrons slow way down.” If the electrons were less dense and slower moving the only possible conclusion was that the current in the resistor was significantly less than the current in the rest of the circuit. This does not coincide with the idea of conservation of charge around the circuit.
The variable current density misconception was held by at least 21 students or about 17% of the class (see Table 4.5). As was the case with any of the misconceptions analyzed, the true frequency was somewhat muddled by the
inability to determine exactly what each student intended with their drawings and written descriptions.

The last misconception analyzed for the resistor question was the external charge misconception. This misconception was very interesting and its origin is open to conjecture. As stated on numerous occasions in this report, the external charge adjacent to a conducting circuit element is essentially zero, thus for the resistor question there should be no charge drawn external to the resistor or connecting wire. Interestingly, a sizable minority of students drew some type of charge or charge particles existing external to the circuit. This was in contrast to the current question in which there were very few such responses.

The first possibility was that the students did not understand the provided drawing locations and how they related to the circuit schematic. This possibility cannot be discounted out of hand, though it was thought to be unlikely. It was verbally explained to the students prior to completing this questionnaire that the drawing locations represented a zoomed in view of the resistor and connecting wire. In addition, this questionnaire was distributed
after the current question which had a very similar graphical layout and few examples of this type of response occurred.

Figure 4.39 was a typical example of the external charge misconception. It can clearly be seen in the three separate drawings that the student had depicted both positive and negative charges outside the resistor. In addition to these external charges there was also a wave-type phenomenon drawn within the connecting wire. The verbal comments of the student did not clarify the nature of the external charges, specifically the student stated for each case, “1 Ohm: There is a steady current with a little resistance. Going into the resistor the current is fast, once it comes out the resistor is slower, then speeds up,” “2 Ohm: More resistance than the 1 Ohm. Going into the resistor the current is fast again. Once it comes out from the resistor is slowly speeds back up,” and “10 Ohm: A lot more resistance than the first two. Going into the resistor the current is fast like the others but once it comes out of the resistor it a lot more slower than the other two. It speeds back up slower.” The student did not elaborate on the existence of external charges and thus the reasoning behind the drawings lies undiscovered.
In Figure 4.40 a slightly different version of the external charge misconception. In the drawings of this example the student again showed some external charge or electricity. For the 1 Ohm case the external phenomenon
was drawn as discrete negative charges. However, for the 2 ohm and 10 ohm cases the external phenomenon was drawn as a wavy line enclosing the resistor. The arrows presumably depicting current flow were drawn inside the connecting wires and through the resistor. This inferred that the student was not being confused by the schematic, but genuinely believed in the external phenomenon around the resistor. Unfortunately, as in the previous example the verbal descriptions did little to enhance the drawings, specifically the student stated, “1 Ohm: Negative electrons move very quickly through the resistor at a fast pace which allows the electricity to move through the wire,” “2 Ohm: Negative electrons move through the resistor at still a rapid rate causing electricity to go through the wires,” and “10 Ohm: Negative electrons are moving rapidly through the resistor, but not as quick as 10 Ohm.” These written descriptions did not clarify the meaning of the external phenomenon.
As previously stated, the number of students demonstrating the external charge misconception was not insignificant. In fact, a total 27 students (about 22% of the participants) demonstrated this misconception. Unlike
many of the other misconceptions, this number should be very accurate due to the lack of ambiguity in the associated drawings.

Table 4.5

Comparison of Students With and Without Resistor Misconceptions on Final Course Grade.

<table>
<thead>
<tr>
<th>Misconceptions</th>
<th>Without</th>
<th>With</th>
<th>Z</th>
<th>p &lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External Charge</td>
<td>82%</td>
<td>80%</td>
<td>0.64</td>
<td>ns</td>
</tr>
<tr>
<td>n</td>
<td>98</td>
<td>27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable Speed</td>
<td>80%</td>
<td>83%</td>
<td>1.62</td>
<td>ns</td>
</tr>
<tr>
<td>n</td>
<td>77</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable Current Density</td>
<td>81%</td>
<td>78%</td>
<td>1.78</td>
<td>ns</td>
</tr>
<tr>
<td>n</td>
<td>104</td>
<td>21</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When student misconceptions were compared to final course grades in Table 4.5 it was determined that all observed differences were not of statistical significance and thus the null hypothesis was retained.

**Concepts Demonstrated**

Another method that can be employed to classify student responses was based upon the concepts demonstrated
in their answer. This method was proposed by Pardhan and Bano in their 2001 article to the *International Journal of Science Education*. Even if a student does not correctly answer a question, he or she may still demonstrate some correct conceptual ideas. A hierarchy of concepts can be created and student responses categorized based upon how many of these concepts they demonstrate.

**Light question.** For the light question, we are interested in what concepts the students demonstrate concerning light and light/matter interactions that are correct. Correct was defined as acceptable explanations for an introductory physics course. It was not feasible to assume that the Physics 101 students would have any means of describing light and matter interactions using the approaches of quantum theory.

There are, however, some concepts we would expect the students to demonstrate following their instruction during the Physics 101 course and through general environmental experience. Based upon review of the student question sheets the following list was created to classify student conceptions.

- Light travels in straight lines.
• Law of reflection.
• Law of refraction (Snell’s Law).
• Seeing.

The first conception that would be expected from most of the students was that light traveled in straight lines. Diffraction phenomenon is negligible on the scale of the drawing represented on the questionnaire. Any experience the students have had with light should reinforce the notion of straight line travel. The law of reflection should also be familiar to students through daily interaction with mirrors. In addition the students were exposed to this idea during class lectures and laboratory activities prior to the administration of the light question. The law of refraction is slightly less intuitive. Students should have some familiarity with the idea that transparent materials tend to bend or deflect light waves. This is most commonly experienced through the famous straw in a glass cup filled with water observation. Additionally, the students were exposed to the law of refraction through the Physics 101 course. The last conception that was analyzed during this section was the conception of seeing. In essence we can only see what
reaches our eyes. In accordance with this fact the student should draw some rays leaving the glass or wood (either through reflection or transmission) if they state that the object will appear a certain way (i.e. color), otherwise it would be invisible.

The most basic concept the students were expected to demonstrate was that light travels in straight lines. As was expected the vast majority of students demonstrated this concept through their verbal descriptions, and more importantly their drawings. Of the 130 students completing the light questionnaire, 111 used straight line depictions for their light rays, this constitutes approximately 85% of the respondents. Figure 4.41 shows a student that drew light rays which traveled in a straight line. This type of representation was predominant in the data set.
Much less common (only \( \approx 15\% \)) were students representing light as something other than a straight line. There were examples of students drawing light as curving
while transmitting through the air. Figure 4.42 was a representative example of this case.

Some of these cases may have been the result of poor artistic skills, but others seemed to show intent on the
part of the student. Figure 4.43 was one such interesting representation of light rays.

Here we see that the student depicted light rays with curvy or sinusoidal shaped lines. This example was
interesting because the student depicted the three different colors uniquely. It may be assumed that the student was just trying to convey the wave nature of light in this example; however, there are some inconsistencies if this was the case. The blue light ray was depicted using a conventional sinusoidal form. This is standard practice for wave representation. The red light ray was depicted by a curly type repeating pattern, clearly periodic in nature but different from the depicted wave form of blue light. Lastly, the green light was drawn as only a straight line. If the student meant to depict light as waves, it was unclear why three different approaches were used for the three different rays.

The law of reflection is a concept that most students should be familiar with. The law of reflection was covered during the Physics 101 course and can be inferred from daily interaction with mirrors. Of the 130 questionnaire sheets completed for the light question, 55 demonstrated the law of reflection properly. This was about 42% of respondents. Since some students did not believe there were any reflected rays, they did not try to draw or verbally describe them. Consequently, not all the students failing to demonstrate this concept did so through
erroneous understanding of reflection. The general idea for this concept, since the student produced a two-dimensional drawing, was that the incident angle of light should be equal to the reflected angle. Figure 4.44 was a characteristic example of a student correctly demonstrating the concept of reflection.
It can easily be observed that when the student believed light reflected, the rays were drawn with the angles of incidence and reflection being approximately equal. This was sufficient to correctly demonstrate the
principle of reflection. In Figure 4.45 the student did not correctly express this principle. In this example the student incorrectly believes that light was reflected 360 degrees when incident at angles other than 90 degrees.

Figure 4.45. Example of an incorrect depiction of reflection.
The law of refraction, or Snell’s Law, is less intuitive than the law of reflection. The students were introduced to this principle during the Physics 101 course, and there is some environmental exposure during daily life. Of the 130 students completing the light questionnaire, 48 correctly demonstrated the law or refraction. This correlates to about 37% of the respondents. In order to demonstrate this concept, the student had to show that the light rays change direction upon crossing a boundary between two different media. In Figure 4.46 the student correctly demonstrated the nature of refraction for the light rays that cross media boundaries. It can clearly be seen in cases I and 2 that the light rays changed direction upon hitting the glass and then again upon reentering the air.
Figure 4.46. Example of the law of refraction.

Figure 4.47 was fairly typical of the students that had not demonstrated the concept of refraction correctly. This student stated in case 1, “Since the glass is transparent, the colored light will continue its normal
path.” In effect, the student was saying that the light would not change direction, or refract, upon crossing the boundaries between glass and air. The pictorial representation was true to the verbal description, the light rays continued traveling in the same direction as they passed through the glass. This type of representation was observed in the majority of student responses.
The last concept listed was the nature of seeing. Due to the rather nondescript name this concept requires some explanation. The important idea here was that we can only visually perceive what reaches our eyes. In order for an object to appear blue, then blue light rays must reach our
eyes. Additionally, not only must blue light rays reach our eyes, but other wavelengths of color must not reach our eyes. In order to correctly demonstrate this principle, the student must be consistent between what color they are saying the object appears to be, and what type of rays they show exiting (either through reflection or transmission) the object. Out of the 130 students that completed the light question, 68 students demonstrated this concept. This represented a little over half of the students (roughly 52%). Figure 4.48 was a good example of a student that correctly demonstrated this principle. In case 1 the student stated, and pictorially showed, that all the colors transmit through the glass resulting in a colorless object. In case 2 the student correctly showed that only the blue light was transmitted through the blue colored glass, while stating the other two colors were absorbed. This would result in a blue colored transparent object. In case 3 the student stated, “The blue is the only color reflected back the red and green are absorbed.” Once again the student understood that for the object to appear blue it must either have reflected or transmitted that color. In this case since the object was opaque it reflected blue light. This example was typical of the students that correctly
demonstrated this concept. However, this student, like many others, failed to provide an explanation of why certain colors were reflected, transmitted, or absorbed.
Figure 4.49 was an example of student work that was deficient in the concept of seeing. In case 2 the student stated, “I believe the red will be reflected, blue absorbed, and green transmitted.” In the given description for case 2 it stated that the glass was transparent and blue. The student’s description and pictorial representation of the problem would result in an object that was colored red when viewed from the incident side and colored green when viewed from the opposite side. In no case would this object appear blue, because the student stated that blue light was absorbed. In case 3 the student stated, “I believe all three (colors) will be reflected.” The problem statement says that the object was opaque and blue. The student’s answer would produce an object that was mirror like and would be the same color as the incident light, in this case white. In case 1 the student was correct in stating that the three colors would be transmitted, resulting in a colorless, transparent object. For this particular concept, unlike the first three, it was decided that only cases 2 and 3 would be analyzed. This was due to many students stating that all rays would transmit in case 1, but demonstrating lack of understanding in the slightly more complicated cases 2 and 3.
Current question. For the current question there were multiple correct conceptions that the students could have demonstrated. In order to make the analysis for this
portion feasible, three important concepts were chosen to be quantified.

The first concept to be analyzed was known as “discrete charge carriers.” Current is defined as the amount of charge passing a particular point, in a certain amount of time. The charge that passes the point occurs in discreet amounts. This quantum of charge is equal to \(-1.602 \times 10^{-19}\) coulombs. The physical entity carrying this charge is called the electron. In this data set many of the students drew discreet units (mostly electrons but sometimes protons) as the charge carrying entities. However, many other students drew the current as a continuous wave type phenomenon.

Figure 4.50 was a typical example of a student that demonstrated the discrete charge conception. In case 1 the drawings for A, B, and C all showed individual distinct charges, both positive and negative. The idea of discrete charge was further explained in the verbal description, specifically the student stated for case 1, “A: While off the protons + electrons will be even,” “B: While off the protons and electrons will be even,” and “C: While off the protons and electrons will be even.” This was essentially
correct for each situation. By using the terms protons and electrons, the student reinforced the idea of discrete charges. In cases 2 and 3 the student erroneously abandoned the idea of evenly distributed charge but retained the idea of discrete charges. Most of the students that demonstrated this concept produced very similar work. The primary difference was that many of the students did not draw specific borders, instead they simply drew “+” and “−” to represent charged objects.
Figure 4.50. Example of the discrete charge conception.

Figure 4.51 shows a student response that had not correctly demonstrated the idea of discrete charge. In case 2 the student drew an assortment of straight lines. In section A the lines were perpendicular to the wire edges.
and spaced relatively far apart. In section B the lines crossed to make an “X” type pattern. In section C the lines were close together and drawn at different angles.

The verbal descriptions for case 2 were as follows, “A: The currents are moving evenly through the battery,” “B: The currents are moving faster and crossing each other,” and “C: The currents are moving fast through the battery.”

There was no mention of discreet charge carriers in the verbal descriptions. Interestingly, the student mentioned “currents,” a plural version of current, the usual way to describe the flow of electrical charge in a wire. When comparing the drawings and verbal descriptions, it appears that each straight line represented a single “current.” This was an interesting description of current that did not employ discrete charge carriers.
The discrete charge conception was demonstrated by a majority of students in the Physics 101 class. The types of responses observed in this data set were similar to responses observed in other research projects (Kibble,
The students in this data set had been exposed to the idea of charged objects (electrons and protons) during the Physics 101 course and undoubtedly in their prior academic experience.

As previously discussed (see section on charged wire misconception), a wire carrying current does not become appreciably charged itself. The numbers of electrons and protons in the wire remains virtually constant during the time it carries current. A minority of students correctly demonstrated this conception either verbally, pictorially or both.

Figure 4.52 was an example of this concept demonstrated correctly. In case 1 the student stated, “A: The charge is neutral when the switch is off,” “B: The switch is off causing the wire to create no charge,” and “C: The charges cancel each other out.” The student never mentioned that the wire was charged or there were excess amounts of charge existing in the wire. In addition, the drawings clearly depicted equal amounts of positive and negative charge at locations A, B, and C. The general theme of case 1 was continued through cases 2 and 3.
Figure 4.52. Example of the equal charges conception.

Figure 4.53 was a typical example of a response sheet showing a non-equal distribution of charge throughout the wire. In case 2 the student stated, “A: Since the light was just switched on, electrons start to circulate,” “B:
Once it has been on more electrons start to circulate,” and “C: Once all the way turned on there are a lot of electrons present.” The accompanying diagrams only showed negative charge, presumably electrons. According to this drawing, the wire would become highly negatively charged when passing current and neutral when there was no current flowing (see case 1). Case 3 was a continuation of case 2, but the student believed that there was even more current flowing. In the majority of cases when the student did not describe a situation of equal charge, he or she described a situation of excess negative charge resulting in a net negative charge on the wire. The cases where students described only positive charges were much less frequent.
The last concept analyzed for this portion of the report was the moving negative charge concept. As has been stated repeatedly through this chapter, it is moving negative charges, namely electrons, which carry the current.
through the wire. The student needed to correctly exhibit knowledge of this fact to have been categorized as demonstrating this concept.

Figure 4.54 shows a questionnaire that correctly demonstrates the moving negative charge conception. In case 1 the student stated, “A: Electrons flow from the light to the battery,” “B: Electrons flow from the switch to the bulb,” and “C: They also flow from the switch to the battery.” The verbal description made it very clear that electrons and hence negative charge were what was moving. The pictorial representations for section A, B, and C also showed only negative charges moving. This example was very representative of students’ work that correctly demonstrated the moving negative charge concept.
The majority of students had not so clearly demonstrated that negative charge moved and positive charge did not. Figure 4.55 was a typical example of such a case. In case 1 the student stated, “A: There is current flowing
through A to the light bulb,” “B: The current is flowing downward towards the light switch,” and “C: Current still flows since it’s plugged in but nothing happens.” Through this verbal description there was no explanation as to which type of charge was flowing. The pictorial representations also did not specify whether it was positive or negative charge that was moving.
Students that had not demonstrated the moving negative charge concept generally postulated that it was positive charges that were moving, a minority of students produced work similar to Figure 4.55.


Resistor question. For the resistor question, as in the case of the other two questions, there were a great many correct concepts the students could have demonstrated. Many of these concepts were also applicable to the current question due to the similarity in phenomenon. This particular question was different from either the light question or the current question due to its higher level of difficulty. The students had more exposure to both the interaction of light with objects and the nature of current flow than with the phenomenon of resistance. Because of this there was a much lower frequency of concepts demonstrated correctly than with the other two questions.

Two concepts were deemed important enough to quantify based upon the frequency of occurrence and importance to understanding the phenomenon of resistance. Frequency of occurrence was important because without a sufficient number of questionnaires to analyze, a statistical analysis would not be valid. The two concepts that met these criteria were negative discreet charge carriers and proportionality between resistance and current flow.

The first concept analyzed was the negative discreet charge carrier model. This concept was virtually identical
to one analyzed for the current question. This similarity will allow some comparison between the number of students demonstrating the concept in this context as opposed to within a simple wire. As has been stated throughout this report, charge carriers in a simple circuit consist of moving electrons or moving discrete negative charges. In order to correctly demonstrate this concept the student had to either draw or verbally describe discrete negative charge carriers. It was not important if the student described the movement of these charge carriers correctly, only that the student understood the existence of such charge carriers.

Figure 4.56 clearly demonstrates the negative discreet charge carrier concept. The drawings for each case clearly showed that the student believed the current consisted of discreet negatively charged particles. The verbal description was consistent with this interpretation. The student stated, “1 Ohm: Least resistance. This would be faster because electrons could flow easier,” “2 Ohm: The flow is getting faster. There are few electrons” and “10 Ohm: More resistance. This would mean that there are numerous electrons that slow it down.” These statements made it clear that the student believed electrons were the
charge carrying entity and thus this questionnaire successfully exhibited the conception of discreet negative charge carriers. It should be noted that the student was completely incorrect in the placement of the negative charges and the verbal descriptions were also inaccurate, however, that was immaterial in this circumstance.
A slightly different version of the discreet negative charge carrier conception was demonstrated in Figure 4.57. In this example the student was more accurate in the overall description of the phenomenon than in Figure 4.56.
The drawings clearly showed discreet negative charges moving through the resistor. The number of charges was consistent across the three different resistances but the speed was different. The verbal descriptions did not add significant information to the drawings, they merely reaffirmed that charge was moving through the resistors. Once again even though the student description was lacking in many details, it did successfully demonstrate that charge carriers in this type of circuit were discreet and negative.
The second concept analyzed was proportionality between resistance and total current flow. Fundamentally this was equivalent to Ohm’s Law (see Equation 3.18). For a simple circuit such as the one depicted on the resistor
questionnaire sheet, there was an inverse proportionality between resistance and total current, or in simple terms, the greater the resistance the less the current. In the particular case of this questionnaire, the current was the greatest for the 1 ohm resistor, half as much for the 2 ohm resistor, and one-tenth as much for the 10 ohm resistor. If the students demonstrated some knowledge, either graphically or verbally, of this decrease in current with increasing resistance, they would then be categorized as demonstrating this conception.

Figure 4.58 was a fairly typical example of a questionnaire correctly demonstrating the concept of proportionality between resistance and current. This particular student chose to represent current flow as continues lines, superficially similar to contour lines. The density of the lines correlated to the quantity of current. Upon inspection of the diagrams it can be observed that the student predicted a decrease of current with increased resistance. This interpretation was enhanced by the verbal explanations provided. The student stated for each case, “1 Ohm: The lines are electric current. The less ohms, the more electric current the resistor lets through,” “2 Ohm: Less lines = less current.
2 ohm would let less current through than one ohm” and “10 Ohm: 10 ohms would not let much electric current through because it has more resistance.” This student had clearly demonstrated an understanding of the relationship between resistance and total current.
Figure 4.58. Example of current/resistance proportional concept.

Figure 4.59 was another example of the proportionality between resistance and current concept. This particular student chose to draw electrical current as dashed lines. The spacing of the dashed lines correlated with amount of
current. From the drawings it could be observed that the student correctly believed that the total current would decrease with increasing resistance. In the verbal description this student also correctly determined the ratio of current decrease. The student wrote, “1 Ohm: If there is less resistance then more current can pass through the resistor,” “2 Ohm: There is twice as much resistance resulting in half as much current,” and “10 Ohm: Since there is ten times as much resistance than the first one (1 ohm case) there is only a tenth of the current.” Obviously this student correctly identified the proportionality between resistance and current and thus was classified as such.
Table 4.6 summarizes the frequency of concepts demonstrated for the three questions.
Table 4.6

Frequencies of Student Conceptions for the Various Questionnaires.

<table>
<thead>
<tr>
<th>Conceptions</th>
<th>n</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Light (N=130)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straight Lines</td>
<td>111</td>
<td>85%</td>
</tr>
<tr>
<td>Law of Reflection</td>
<td>34</td>
<td>26%</td>
</tr>
<tr>
<td>Law of Refraction</td>
<td>48</td>
<td>37%</td>
</tr>
<tr>
<td>Seeing</td>
<td>68</td>
<td>52%</td>
</tr>
<tr>
<td><strong>Current (N=130)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discreet Charge Carriers</td>
<td>79</td>
<td>61%</td>
</tr>
<tr>
<td>Equal Amounts of Charge</td>
<td>29</td>
<td>22%</td>
</tr>
<tr>
<td>Moving Negative Charge</td>
<td>10</td>
<td>8%</td>
</tr>
<tr>
<td><strong>Resistor (N=125)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discrete Negative Charge</td>
<td>40</td>
<td>32%</td>
</tr>
<tr>
<td>Current/Resistance Relation</td>
<td>26</td>
<td>21%</td>
</tr>
</tbody>
</table>

First analyzing the light question results, as expected a vast majority of the students demonstrated the concept that light travels in straight lines. The law of reflection had the fewest number of students confirm knowledge of it. This was partially caused by the fact that a sizable minority of students did not believe any light reflected in any of the three cases. This presumption was incorrect, but certainly contributed to
lowering the percentage of students falling into this category. Only about 37% of the students demonstrated knowledge of the law of refraction. Virtually all students knew that light would penetrate the glass in cases I and 2, however almost two thirds of them did not show the light refracting. Slightly over half of the students showed that they understood the nature of seeing. The students that did not fall in this category generally depicted all the light as being absorbed, or less frequently the wrong colors being reflected or transmitted.

With regards to the current question the concept the most students correctly demonstrated was the discrete charge carrier concept. Almost 61% (79 total students) of the Physics 101 students demonstrated knowledge of current being carried by discreet objects. The majority of students not falling into this category tended to represent electrical current as the manifestation of some sort of energy wave or spark. Fewer students were able to successfully demonstrate the equal amounts of charge conception. Only 29 students clearly showed knowledge of the fact that the conducting wire contains virtually equal amounts of positive and negative charge. This amounts to 22.31% of student respondents, or slightly less than a
fourth of the class. The majority of students not demonstrating this concept tended to draw an excess amount of negative charge. Much fewer students drew an excess amount of positive charge, or did not mention charge at all, instead resorting to the previously mentions waves and sparks. Very few students were able to correctly demonstrate that negative charges move when conducting current passes through a wire. Out of the 130 students completing the questionnaire, only 10 correctly demonstrated that negative charges move. This by no means implies that only 10 students know that negative charges move, it only means that 10 students correctly described such movement on their question sheet.

Examining the resistor question it was observed that the concept students most frequently demonstrated was the discreet negative charge carrier concept. In total 40 students, or 32% of the participants, were able to successfully demonstrate this concept. This was interesting because it was significantly less than the percentage of students that were able to demonstrate the discreet charge carrier concept for the current question. For the current question approximately 61% of students successfully demonstrated the concept. The presence of the
resistor apparently had a detrimental effect on students’ conceptual modeling of the situation. Ultimately, more students drew waves or “sparky” phenomenon for this question than in the current question.

A smaller percentage of students were able to demonstrate proportionality between current and resistance. Out of 125 participants only 26 showed evidence of understanding that resistance would directly affect the amount of total current. This amounts to only about 21% of the total participants. The vast majority of students simply drew the same amount of current for each of the three different scenarios. The low frequency of students correctly demonstrating these concepts underlies the fact that responses for this question were generally of inferior quality when compared to the other two. The possible reasons for this are manifold. The nature of resistance in materials is extremely complicated and the students could not be expected to understand it on anything more than a superficial level. Additionally, the discussion of resistance during course lecture was less substantive than the discussion of either light or current flow.
<table>
<thead>
<tr>
<th>Total Concepts</th>
<th>n</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light (N=130)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Concepts</td>
<td>13</td>
<td>10%</td>
</tr>
<tr>
<td>One Concept</td>
<td>36</td>
<td>28%</td>
</tr>
<tr>
<td>Two Concepts</td>
<td>39</td>
<td>30%</td>
</tr>
<tr>
<td>Three Concepts</td>
<td>21</td>
<td>16%</td>
</tr>
<tr>
<td>Four Concepts</td>
<td>21</td>
<td>16%</td>
</tr>
<tr>
<td>Current (N=130)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Concepts</td>
<td>48</td>
<td>37%</td>
</tr>
<tr>
<td>One Concept</td>
<td>48</td>
<td>37%</td>
</tr>
<tr>
<td>Two Concepts</td>
<td>32</td>
<td>25%</td>
</tr>
<tr>
<td>Three Concepts</td>
<td>2</td>
<td>2%</td>
</tr>
<tr>
<td>Resistor (N=130)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Concepts</td>
<td>63</td>
<td>50%</td>
</tr>
<tr>
<td>One Concept</td>
<td>58</td>
<td>46%</td>
</tr>
<tr>
<td>Two Concepts</td>
<td>4</td>
<td>3%</td>
</tr>
</tbody>
</table>

The total number of concepts each student demonstrated can also be tabulated. Table 4.7 was a chart depicting the number of concepts each student established for each question. For the light question only 10% of the students were unable to show knowledge of at least one concept. The
number of concepts most frequently shown on a light questionnaire was two, closely followed by one. Only about 32% of students demonstrated more than two concepts for this question.

For the current question more than one-third of the class was not able to demonstrate any of the three concepts. These particular students may have demonstrated some correct concepts, but did not demonstrate any of the three concepts analyzed in this section. About 37% of the student respondents demonstrated only one concept. As can be seen in Table 4.7 this was primarily the discrete charge concept. Roughly 25% of the students were able to demonstrate two total concepts. Out of the 130 students only two demonstrated all three concepts on their questionnaires, amounting to a little more than 1% of the respondents.

With regards to the resistor question more than one-half of the class was not able to demonstrate either of the two concepts. These particular students may have demonstrated other correct concepts, but did not demonstrate either of the two concepts analyzed in this section. About 46% of the student respondents demonstrated
only one concept correctly. A very small minority (roughly 3%) of students were able to demonstrate both concepts correctly for this question.

**Correctness Demonstrated**

Though the students were not necessarily expected to answer the questions presented to them for this research project correctly, the answers can still be categorized based upon level of correctness. Following the method utilized by Redfors in his 2001 article to the *International Journal of Science Education*, a Likert scale of correctness can be constructed. Student responses can then be assigned to one of the categories based upon the level of correctness as interpreted by the researcher. This subjective level of correctness analyzes only the students’ statements, both verbal and pictorial and was independent of whether the student was discussing macro or micro phenomenon. The scale chosen for this project consisted of three categories. These categories were labeled numerically from 0 to 2. The higher the number the more correct the answer. The level of correctness was based upon explanations expected of a high school level
physics student. Table 4.8 gives a summary of the categorization criteria for correctness.

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Almost completely incorrect</td>
</tr>
<tr>
<td>1</td>
<td>Contains significant correct and incorrect statements</td>
</tr>
<tr>
<td>2</td>
<td>Almost completely correct</td>
</tr>
</tbody>
</table>

**Light question.** A typical example of student work falling into the “0” category was demonstrated in Figure 4.60. This student’s statements are generally erroneous. In case 1 the student stated, “The light is reflected. It cannot go through the glass.” This was obviously false as the glass was transparent, thus by definition light must have traveled through it. The drawing for case 1 did little to clarify the student’s written statement. In case 2 the student stated, “The light is transmitted. It can go through the glass.” The student was incorrect here because the wavelength of light that can be transmitted was never specified. If all light was transmitted as the student stated, then the glass would be colorless, however, it was
clearly stated in the problem description that the glass was blue colored. Finally in case 2 the student stated, "The light is absorbed. It is taken in by the wood because the wood can’t reflect it. But I don’t know why the wood can’t reflect it." Here again the student was not correct. If the wood did in fact absorb all light as the student stated, it would be black. In the problem description for case 3 it stated that the wood was blue, thus the blue light must be reflected off the surface of the wood. The questionnaire sheets that were categorized as “0” were all similar to this example in their level of correctness.
The questionnaire sheets that were categorized into the “1” category were of a higher quality than the “0” responses. In order to qualify, the response had to be
significantly correct with some mistakes included. Figure 4.61 was a fairly typical example of a category “1” work.

The student was essentially correct in cases I and 3. In case 2 the student stated, “Blue will reflect since the
glass is blue when the red + green will be absorbed”. This was incorrect in that the student did not mention the transmission of blue light. In the problem statement it was clearly stated that the blue glass was also transparent. This answer sheet was a little more correct than perhaps the average “1” rated question sheet, though it was still representative of this type of response.

In order for a questionnaire to be rated “2” it had to be almost completely correct. Only the slightest error was accepted for a “2” category paper. In Figure 4.62 a typical example of a category “2” questionnaire was presented.
It can clearly be observed that the student’s statements for this questionnaire were generally correct. Though the student did not explain what was happening on a microscopic level, the explanation of macro phenomenon was
generally correct. This example was representative of the thirty responses falling into the “2” category.

**Current question.** For the current question the procedure of classification was the same, though of course the subject matter was different. For the current question Figure 4.63 was an example of level “0” work. As previously stated, level “0” work was almost entirely wrong. The pictures correlating to case 1 were simply parallel lines with arrow heads. The verbal descriptions for case 1 were, “A: Electricity is flowing freely through the wires,” “B: The electricity is still flowing freely through the wires,” and “C: The electricity is flowing through the wires.” These statements and drawings were entirely wrong. In case 1 the switch was open, hence there was no current flowing through any section of the wire. In case 2 the student stated, “A: Not as much electricity is running through the wires,” “B: Not much electricity is running through the wires,” and “C: End of electricity is running out.” Once again these statements were incorrect. The student stated that not as much electricity was running through the wire as in case 1, where in fact there was no electricity running through the wires. The statement of electricity running out in part C was particularly
incorrect. In case 3 the student stated, “A: No
electricity is flowing through the wires,” “B: Nothing is
happening in the wires,” and “C: No electricity is running
through the wires.” Of course these statements were
incorrect in that the circuit was closed and there should
be a steady state flow of current in A, B, and C for case
3. As in cases I and 2, the pictorial representation in
case 3 was incorrect in that it did not depict discreet
charge carriers, in fact there was no mention of charges at
all. This was fairly representative of “0” level work.
Students in this category showed general confusion on all
aspects of the current question.
Figure 4.63. Example of “0” level work.

Figure 4.64 was a typical example of level “1” work. While the pictorial representations in this example were wrong, the verbal descriptions had a certain level of correctness to them. In case 1 the student stated, “A:
Electricity is traveling f/ (from?) the battery to the light,” “B: No activity because the switch is off,” “C: Electricity travels f/ (from?) the battery to the switch.” The student was correct in the statement for part B, but was incorrect in parts A and C. For case 2 the student stated, “A: Electricity travels f/ (from?) the battery to the light,” “B: Electricity travels f/ (from?) the switch to the light,” and “C: Electricity travels f/ (from?) the battery to the switch.” Here the student was generally correct in stating that electrical current was flowing at positions A, B, and C. The student was incorrect in stating that the current moved in two different directions. In case 3 the student continued the theme of case 2. However, the student was correct in recognizing that cases 2 and 3 were in fact the same situation. This example shows that in order to be classified “1” the student had to demonstrate some aspects of correctness. There also had to be a significant level of incorrect statements, as can be easily seen in Figure 4.63.
Figure 4.65 was an example of “2” level work. Level “2” work needed to be mostly correct, possibly with some small errors. The drawings in cases I, 2, and 3 demonstrated the existence of discreet charge carriers and
also that there were roughly equal numbers of positive and negative charges (with some exceptions). In case 1 the student stated, “There is no current moving through the wire.” This statement was correct as the circuit was open in case 1. For case 2 the student stated, “Current moving through the wires (electrons moving through).” The student correctly stated that current was moving through the wires in this case and additionally that electrons were the charge carrying entities. In case 3 the student stated, “Same as #2 Current (electrons) moving through the wire.” This was fundamentally correct because the circuit was closed and current was flowing. This type of response was fairly representative of type “2” answers. This category of answer was generally correct with varying small problems. A common problem observed was confusion between positive and negative charges.
Resistor question. With regards to the resistor question Figure 4.66 was an example of “0” level. As previously stated, level “0” work was almost entirely wrong in its assumptions and conclusions. For the 1 ohm case the
student simply drew a single curved arrow along the inside lower surface of the resistor. The accompanying verbal description was, “This one the arrow is on the left side going where length and going to right.” There was little if any useful information to glean from either the drawing or description for this case. In the 2 ohm case the student drew two arrows along the upper inner surface of the resistor. The written description for this case was, “There are two arrows at the top going toward the bottom. There is two arrows for two ohm.” Apparently the student sought to correlate the resistance, in ohms, with the number of arrows within the resistor. The physical parallel to this scheme was not evident. For the 10 ohm case the student reverted again to one arrow, though this time it was across the top inner surface of the resistor. The written description for the 10 ohm case was as follows, “There is a long arrow going to the bottom from left to right. It is long because of the 10 ohms.” Now the student had disregarded the relationship between resistance and number of arrows for a new relationship between resistance and length of arrows. In the end this questionnaire was completely incorrect in both its explanation of micro and macro events within and around the
resistors. Because of the complete lack of correct statements this questionnaire was rated “0” on the correctness scale. This example was of lower quality than the average “0” rated question sheet but was similar in level of correctness.

Figure 4.66. Example of “0” level work.
An example of “1” level work was shown in Figure 4.67. In the drawings the student represented the charges as discreet units, however, it was never specified what the charge on each element was. In this example the density of the moving charges tended to increase with increasing resistance. This was a very common scenario in the resistor question data set. It was postulated that perhaps the students were using a “traffic flow” analogy inappropriately. The major error in this questionnaire comes in the written descriptions, the student stated, “1 Ohm: This has the least amount of resistance so therefore there is not much current flow,” “2 Ohm: This is in between and has an average amount of resistance so therefore the current flow is average,” and “10 Ohm: This has the greatest resistance therefore it has the greatest amount of current flowing.” The student correctly identified that there was a relationship between resistance and current. However this relationship was believed by the student to be the opposite of reality. The student predicted that current would increase with increasing resistance; this was patently false and reduced this questionnaire sheet from a possible “2” rating to a moderately correct “1”.

-309-
Figure 4.68 was an example of a question sheet that was ranked "2" on the correctness scale. In the drawings for this questionnaire the student had drawn what appeared to be negative charges throughout both the resistor and...
connecting wires. Unfortunately, the density of the presumably moving charges increased as the resistance increased implying a greater current or at least an equalization of the “slowing” of current the student discussed. Specifically in the written portion of the questionnaire the student stated, “1 Ohm: The current moves through the resistor with a little resistance, but moves through somewhat easy,” “2 Ohm: This resistor has a little more resistance than the first, but still allows the current to flow,” and “10 Ohm: This has the most resistance, the current cannot flow through it freely, and is slowed down.” These statements were consistent with Ohm’s law but not necessarily consistent with the accompanying drawings. In spite of a possible lack of consistency between the verbal and pictorial representations, this questionnaire was still mostly correct and thus was ranked as “2” on the correctness scale.
Obviously this type of categorization was subjective in nature and may have been slightly different if performed by another investigator. Table 4.9 was a presentation of the
frequency of responses tabulated for each category and questionnaire.

Table 4.9

Correctness Frequencies for the Three Different Questions.

<table>
<thead>
<tr>
<th>Correctness</th>
<th>n</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light (N=130)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;0&quot;</td>
<td>51</td>
<td>39%</td>
</tr>
<tr>
<td>&quot;1&quot;</td>
<td>49</td>
<td>38%</td>
</tr>
<tr>
<td>&quot;2&quot;</td>
<td>30</td>
<td>23%</td>
</tr>
<tr>
<td>Current (N=130)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;0&quot;</td>
<td>75</td>
<td>58%</td>
</tr>
<tr>
<td>&quot;1&quot;</td>
<td>30</td>
<td>23%</td>
</tr>
<tr>
<td>&quot;2&quot;</td>
<td>25</td>
<td>19%</td>
</tr>
<tr>
<td>Resistor (N=130)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;0&quot;</td>
<td>98</td>
<td>78%</td>
</tr>
<tr>
<td>&quot;1&quot;</td>
<td>24</td>
<td>19%</td>
</tr>
<tr>
<td>&quot;2&quot;</td>
<td>3</td>
<td>2%</td>
</tr>
</tbody>
</table>

For the light question it can be seen that the incorrect category was the largest, closely followed by the partially correct category. The percentage of students demonstrating no significant errors was slightly less than a quarter of total students. For the current question it
can be observed that the “0” category has the highest frequency at 75 students or approximately 57% of the Physics 101 class. The second largest category was category “1”, at 30 students or about 23% of the class. The smallest category was the “2” category with 25 students or roughly 19% of the class. For the resistor question it can be observed that the “0” category has the highest frequency at 98 students or approximately 78% of the Physics 101 class. The second largest category was category “1”, at 24 students or about 19% of the class. The smallest category was the “2” category with 3 students or roughly 2% of the class.

**Effect of Prior Physics Exposure**

There have been many studies conducted on whether there is a positive correlation between taking a physics course in high school, and subsequent performance in college physics courses. The results from these studies have been somewhat ambiguous. Certain researchers have found that taking high school physics does tend to improve students’ performance in college physics (Hart & Cottle, 1993; Alters, 1995), while other researchers have found that the effect of high school physics was negligible on
college physics grades (Au & Sharma, 2007). Perhaps the most exhaustive study on the issue was conducted in 2001 by Philip Sadler and Robert Tai. They found that there was a positive correlation between exposure to physics in high school and performance in college level physics. However, the strength of this effect was only about half of what other researchers had found. One of the primary difficulties in investigating the effect of high school physics on subsequent student performance is the vast difference in high school teacher content knowledge and teaching efficiency. This fact is very difficult to control for in research studies on the subject.

On the first day of the Physics 101 course the students completed a demographic survey documenting their high school education experience (see Appendix 3). Of the 132 students that completed the demographic survey, 51 stated that they had taken some form of high school physics. This represents roughly 39% of the total enrolled students. Students were included in the physics category if they reported having taken a dedicated physics course or an integrated physics/chemistry course, a popular course offering in the state of Indiana secondary education system.
It was generally assumed by the primary investigator that the students whom had taken high school physics would perform in a superior manner when compared to the students with no physics background. This was believed primarily because the Physics 101 course was a low level introductory physics course (Appendix 7) and does not present any material above the high school physics level. Effectively, for students with a good high school physics background the Physics 101 course should have generally been a review.

In accordance with these assumptions, the data showed a higher mean final grade for the students exposed to physics in high school when compared to the students with no high school physics exposure (see Table 4.10).

Table 4.10

Effect of High School Physics on Final Grade.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Number of Students</th>
<th>Mean Final Grade (%)</th>
<th>Standard Deviation</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>High School Physics</td>
<td>51</td>
<td>81.5</td>
<td>10.94</td>
<td>119.63</td>
</tr>
<tr>
<td>No High School Physics</td>
<td>81</td>
<td>78.97</td>
<td>10.08</td>
<td>101.67</td>
</tr>
<tr>
<td>All Students</td>
<td>132</td>
<td>78.93</td>
<td>10.40</td>
<td>108.10</td>
</tr>
</tbody>
</table>
Table 4.10 shows that the mean final grade for students with high school physics was 2.5 percentage points higher than for students without high school physics.

When the values from Table 4.10 are used to calculate statistical significance, the result was a $Z_{\text{obtained}}$ value of 1.31. This was clearly less than the $Z_{\text{critical}}$ value of ±1.96. In this case, the null hypothesis of no difference must be retained. Thus even though our mean values show that on average students taking physics in high school slightly outperformed students without high school physics, this was not clearly indicative of a significant difference in ability between groups.

Even though student academic performance did not seem to be affected by high school physics exposure, perhaps student misconceptions were.
Table 4.11
Associations Between High School Physics and Student Misconceptions.

<table>
<thead>
<tr>
<th>High School Physics and Misconceptions</th>
<th>Per Student</th>
<th>Z</th>
<th>P  &lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Light</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With HS Physics (n=51)</td>
<td>0.28</td>
<td>2.03</td>
<td>0.05</td>
</tr>
<tr>
<td>Without HS Physics (n=81)</td>
<td>0.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Current</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With HS Physics (n=51)</td>
<td>1.25</td>
<td>0.77</td>
<td>ns</td>
</tr>
<tr>
<td>Without HS Physics (n=81)</td>
<td>1.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Resistor</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With HS Physics (n=49)</td>
<td>0.78</td>
<td>0.43</td>
<td>ns</td>
</tr>
<tr>
<td>Without HS Physics (n=73)</td>
<td>0.73</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In table 4.11 the number of misconceptions per student was simply an arithmetic mean. In order to test if these results were statistically significant the standard significance analysis was performed. Once again a standard 95% confidence interval (α = 0.05) will be used, resulting in a \( Z(\text{critical}) \) of ±1.96.

When misconceptions retained by students on the light question were checked against exposure to high school physics it was observed that students with high school
physics demonstrated significantly less misconceptions on average than students without high school physics exposure. The apparent relations between high school physics exposure and average misconceptions on the current and resistor questions were not statistically significant.

Previously the idea of epistemological representation was discussed and student responses were classified into a three-tiered framework. In Table 4.12 the results of the epistemological representation classification are shown as they relate to whether or not the student took a high school physics course. The summation of representation coding variables column represents an arithmetic sum of coding variables for the student’s representation of the three cases for this particular question.
Table 4.12

**Associations Between High School Physics and Epistemological Representation.**

<table>
<thead>
<tr>
<th></th>
<th>Per Student</th>
<th>Z</th>
<th>P &lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High School Physics</strong> and <strong>Epistemological Representation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With HS Physics (n=51)</td>
<td>0.73</td>
<td>0.21</td>
<td>ns</td>
</tr>
<tr>
<td>Without HS Physics (n=81)</td>
<td>0.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With HS Physics (n=51)</td>
<td>1.27</td>
<td>1.60</td>
<td>ns</td>
</tr>
<tr>
<td>Without HS Physics (n=81)</td>
<td>0.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With HS Physics (n=49)</td>
<td>1.63</td>
<td>0.68</td>
<td>ns</td>
</tr>
<tr>
<td>Without HS Physics (n=73)</td>
<td>1.44</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When epistemological representation was compared to high school physics exposure it was found that there was no significant relationship for any of the tested questions.

Previously the frequency of concepts demonstrated by students was discussed. It was observed that most students successfully demonstrated at least one concept. An interesting proposition was whether having high school physics exposure would increase the frequency of demonstrated concepts. In Table 4.13 the frequency of...
conceptions demonstrated was shown for both students with high school physics and students without.

Table 4.13

Associations Between High School Physics and Concepts Demonstrated.

<table>
<thead>
<tr>
<th>High School Physics and Concepts Demonstrated</th>
<th>Per Student</th>
<th>Z</th>
<th>p &lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With HS Physics (n=51)</td>
<td>2.12</td>
<td>1.12</td>
<td>ns</td>
</tr>
<tr>
<td>Without HS Physics (n=81)</td>
<td>1.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With HS Physics (n=51)</td>
<td>1.04</td>
<td>1.55</td>
<td>ns</td>
</tr>
<tr>
<td>Without HS Physics (n=81)</td>
<td>0.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With HS Physics (n=49)</td>
<td>0.61</td>
<td>1.10</td>
<td>ns</td>
</tr>
<tr>
<td>Without HS Physics (n=73)</td>
<td>0.49</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When the number of student demonstrated concepts was compared to high school physics exposure it was determined that there was no statistically significant relationship as demonstrated in Table 4.13.

In a previous section of this chapter the correctness of each questionnaire was subjectively reported. When the
students’ level of correctness was compared to their exposure to high school physics, it can be observed that students with exposure to high school physics perform slightly better on average than students without such exposure (see Table 4.14).

Table 4.14

 Associations Between High School Physics and Correctness.

<table>
<thead>
<tr>
<th>High School Physics and Correctness</th>
<th>Per Student</th>
<th>Z</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With HS Physics (n=51)</td>
<td>0.84</td>
<td>0.28</td>
<td>ns</td>
</tr>
<tr>
<td>Without HS Physics (n=81)</td>
<td>0.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With HS Physics (n=51)</td>
<td>0.65</td>
<td>0.63</td>
<td>ns</td>
</tr>
<tr>
<td>Without HS Physics (n=81)</td>
<td>0.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With HS Physics (n=49)</td>
<td>0.22</td>
<td>0.33</td>
<td>ns</td>
</tr>
<tr>
<td>Without HS Physics (n=73)</td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When student correctness as measured by the criteria used in this project was compared to high school physics exposure it was observed that there existed no statistically significant relationship.
**Light question.** Table 4.15 gives a summary of the results for the light question regarding each analysis as it pertains to high school physics exposure. It can be observed that the only analysis in which it appears that high school physics makes a significant difference in performance was number of misconceptions held. Though the difference was statistically significant, it was quite small, resulting on average of about one-fifth of a misconception per student.

Table 4.15

<p>| Summary of Differences Due to High School Physics Exposure for Light Question. |</p>
<table>
<thead>
<tr>
<th>Category</th>
<th>Difference</th>
<th>$Z_{(obtained)}$</th>
<th>Statistical Significance ($\alpha = 0.05$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Grade</td>
<td>2.5</td>
<td>1.31</td>
<td>NO</td>
</tr>
<tr>
<td>Misconceptions</td>
<td>0.19</td>
<td>2.03</td>
<td>YES</td>
</tr>
<tr>
<td>Epistemological Representation</td>
<td>0.04</td>
<td>0.21</td>
<td>NO</td>
</tr>
<tr>
<td>Conceptions</td>
<td>0.26</td>
<td>1.12</td>
<td>NO</td>
</tr>
<tr>
<td>Demonstrated Correctness</td>
<td>0.04</td>
<td>0.28</td>
<td>NO</td>
</tr>
</tbody>
</table>
Current question. Table 4.16 summarizes the results for the current question with regards to each different analysis performed in addition to the final course grade. Of the four different analyses performed for the current question, none of the observed differences in performance between the students with high school physics and students without high school physics were found to be statistically significant.

Table 4.16

Summary of Differences Due to High School Physics Exposure for Current Question.

<table>
<thead>
<tr>
<th>Category</th>
<th>Difference</th>
<th>Z(obtained)</th>
<th>Statistical Significance (α = 0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Grade</td>
<td>2.5</td>
<td>1.306</td>
<td>NO</td>
</tr>
<tr>
<td>Misconceptions</td>
<td>0.13</td>
<td>0.766</td>
<td>NO</td>
</tr>
<tr>
<td>Epistemological Representation</td>
<td>0.406</td>
<td>1.60</td>
<td>NO</td>
</tr>
<tr>
<td>Conceptions</td>
<td>0.238</td>
<td>1.55</td>
<td>NO</td>
</tr>
<tr>
<td>Correctness</td>
<td>0.09</td>
<td>0.63</td>
<td>NO</td>
</tr>
</tbody>
</table>

Resistor question. Table 4.17 summarizes the results for the resistor question in regards to the different
analysis performed in addition to the final course grade. Of the four different analyses performed for the current question, none of the observed differences in performance between the students with high school physics and students without high school physics were found to be statistically significant. This was similar to the results for the current question.

Table 4.17
Summary of Differences Due to High School Physics Exposure.

<table>
<thead>
<tr>
<th>Category</th>
<th>Difference</th>
<th>Z(obtained)</th>
<th>Statistical Significance (α = 0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Grade</td>
<td>2.5</td>
<td>1.306</td>
<td>NO</td>
</tr>
<tr>
<td>Misconceptions</td>
<td>0.05</td>
<td>0.43</td>
<td>NO</td>
</tr>
<tr>
<td>Epistemological</td>
<td>0.19</td>
<td>0.68</td>
<td>NO</td>
</tr>
<tr>
<td>Representations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conceptions</td>
<td>0.12</td>
<td>1.10</td>
<td>NO</td>
</tr>
<tr>
<td>Demonstrated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correctness</td>
<td>0.03</td>
<td>0.33</td>
<td>NO</td>
</tr>
</tbody>
</table>

It must be taken into consideration that the students completing the questionnaires were concurrently taking the Physics 101 course and exposed to some of the ideas
investigated during the analysis. This may have had a diluting effect on any potential relationship between high school physics exposure and student conceptions as measured in this project.

Performance Disparity Between Forms

As stated earlier, the light question was administered in a slightly different manner than the other two questions. Namely, the light question was distributed in three different forms. The difference between the forms was only in the pictorial representation of the transparent glass. This was performed to see if there was any significant difference in performance based upon contextual framing, as has been observed by some researchers (McCullough, 2004; Mildenhall, 2001).

It was initially believed that the different pictorial representations would result in students’ own pictorial representations varying slightly among the different versions. A statistical analysis of the drawings performed by students was not performed for several reasons. First and foremost, the students’ drawings were not generally of sufficient quality to enable a detailed analysis. For instance, a criterion that was going to be used was whether
or not the light ray drawn by the student crossed a “molecule” represented by an “X” in the drawing. Figure 4.69 demonstrates a typical problem encountered during this type of coding. In this figure the red and blue light rays clearly pass through at least one “X” on their way through the transparent blue glass. However, the green light ray does not actually hit an “X” on its way through the glass. The problem here was trying to discern the intentions of the student. Did the student purposely draw the lines this way, or were they just quickly sketched without thought to whether or not they intercepted the “X” markings? Without the ability to personally interview the student any thoughts concerning his or her intentions are merely speculation and cannot add useful information to this report.

Figure 4.69. Typical example of coding problem.
Instead of trying to code the different forms using this type of method, two different approaches were used to address the question of whether the different pictorial representations had any effect on student responses. The first was a purely qualitative interpretation of the principle investigator. After many hours reviewing this data set for the analysis in this section, it was the opinion of the principle investigator that the different forms did not have an appreciable effect on student performance. The drawings the students produced for this question seemed to be on the whole very similar, regardless of the form the student received. Similarly, the verbal explanations provided by the students seemed to be very similar regardless of the variation in questionnaire forms.

A second more quantitative approach was used to determine if a particular questionnaire form tended to reduce student misconceptions. The data were analyzed and categorized by form for the three misconceptions discussed in this section. The aggregate number of misconceptions recorded for each version of the form was then compared to see if there appeared to be any strong correlation between misconceptions represented and questionnaire forms (see Table 4.18).
From Table 4.18 it can be seen that there was little to no correlation between the questionnaire version and the number of misconceptions observed. Version one did have slightly less misconceptions represented even with one more student response; however, it was the opinion of the principle investigator that this small variance does not represent a statistically significant result due to the subjective nature of coding for misconceptions.

<table>
<thead>
<tr>
<th>Questionnaire Version</th>
<th>Number of Student Responses</th>
<th>Aggregate Number of Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>44</td>
<td>15</td>
</tr>
<tr>
<td>Two</td>
<td>43</td>
<td>19</td>
</tr>
<tr>
<td>Three</td>
<td>43</td>
<td>19</td>
</tr>
</tbody>
</table>
Chapter 5: Conclusion

In order to clarify much of the data presented in the previous seven chapters, the primary insights gained from this research project are briefly discussed in this concluding chapter.

Introduction to Conclusion

This research project was undertaken in order to expand on the literature in physics education research, specifically on the research relating to student conceptions in electromagnetism. There is a growing need to understand the dynamics of student comprehension in physics for a number of reasons. First and foremost is the increasingly technical nature of modern society. It is ever more important that people have a firm understanding of science and the scientific method in order to perform their duties as active and engaged citizens. More thoroughly understanding the nature of student conceptions can increase the ability of educators to efficiently impart the ideas of science on future generations. Secondly, the increasing diversity of the student population has rendered
older methods of instruction and assessment somewhat obsolete. With a wider diversity of students taking physics courses both in high school and college, it increases the burden on the instructors to devise new methods of instruction that are effective for all types of students.

A primary thrust of physics education research has been into student misconceptions. This generally took the form of researchers cataloging student misconceptions as inferred from carefully designed multiple choice testing instruments. The majority of these studies and assessment instruments dealt with misconceptions in Newtonian mechanics. Many interesting and worthwhile ideas were generated by this research into misconceptions. However, the recurring flaw in this research has been a lack of understanding concerning how and why student misconceptions existed. The multiple choice approach to research in this field has both advantages and disadvantages. The advantages are that it is easy to administer, simple to quantify, lends itself to an array of statistical analyses, and is relatively objective. The disadvantages are that the student is relegated to choosing an answer provided by the instrument creator, the generation of false positives,
and a lack of means for the student to explain his or her reasoning.

Demographics are another area where physics education research has been rather narrowly focused. Traditionally research took place using students from introductory algebra or calculus based physics courses. This restricted selection criteria limited the number of students from several important demographic groups. Of specific interest to this research project is the limited number of female and pre-service elementary teachers in previous physics education research literature.

This research project has attempted to correct some of these deficiencies. This study was designed to analyze and reveal patterns in students’ conceptual understanding of various electromagnetic phenomena. In contrast to the multiple choice questionnaires used by previous researchers, this project has used an open-ended question format to facilitate the analysis of student reasoning. The three open-ended questions used for this project were designed after a substantial review of the literature pertaining to student misconceptions in physics (see Chapter 2 for further details). Additionally, the
participant pool for this particular project was overwhelmingly female and consisted primarily of pre-service elementary teachers.

This project was significant for several reasons. The relation between high school physics exposure and subsequent student conceptions concerning electromagnetic phenomena was analyzed. This could potentially lead to more efficient high school physics instruction due to increased knowledge of instructional effects on student conceptions. It was hoped this research might help university instructors to improve their instructional techniques. This would result from increased knowledge of their students’ conceptions and how high school physics may have affected them. An additional benefit was the furthering of the small amount of research on how females conceptualize physical phenomenon and how it might differ from their male counterparts.

Another reason this research project was important was because it investigated student conceptions in electromagnetism specifically. As previously stated, historically most of the research into student conceptions concentrated on Newtonian mechanics. Thus this project
should add significantly to the literature. Another important aspect of the project was that much of what was performed was new. The questions asked have never been asked before, this type of analysis had not been performed before and the demographic groups tested have been underrepresented in the published literature.

**Light Question Summary**

The first question distributed to students was the light question (Appendix 3). The light question was designed specifically to investigate what students believe is occurring between the incident light rays and the glass or wood itself. Unfortunately, many students simply reverted to the ideas expressed in the lecture portion of the course regarding transmission, reflection, and refraction of light. This type of response did little to help in understanding students conceptions of the interaction of light and matter on a quantum scale. However, these types of questionnaires were still useful in much of the other analyses performed throughout the project.

The majority of students’ answers (roughly 75%) were classified as phenomenon-based according to the rubric
created by Driver and her co-authors (1996). A significant minority of responses were relation-based and none were classified as model-based. This result was most likely due to a lack of understanding concerning the nature of scientific inquiry. It is possible that by revising the questionnaire and verbal instructions to the students, the result would change slightly.

There were some common misconceptions within the data set for the light question. Many students believed that color was an intrinsic property of an object. This most likely results from environmental interaction and not academic instruction. Everyday objects are generally illuminated by either sunlight or artificial light that replicates sunlight. Due to this objects tend to always look the same color (with small differences between incandescent, fluorescent, and LED light sources) when illuminated. These students thought that the inherent color of the object would affect the incident light beam. This is the reverse of how physicists approach the nature of color.

Another very common misconception concerned why an object appears a certain color. A significant number of
students believed that for an object to appear a particular color it needed to absorb that specific wavelength of light. This misconception showed a lack of understanding in how the human eye perceives color. This may also be due to environmental experience such as adding color dye to water.

A misconception that was observed in this data set and had not been reported in the literature concerned the fate of absorbed light. A small amount of students believed that no light is absorbed, it was all transmitted. However, certain wavelengths were “made dark” by the material as they passed through it. Being “made dark” was apparently analogous to being made invisible. It is difficult to speculate on the origins of this misconception without further research.

When students having any of these misconceptions were compared to students without the misconception in terms of final course grade there was no significant difference. This implied that holding these particular misconceptions did not significantly affect overall academic performance or there were other mitigating factors that served to balance any negative effect. One possibility has to do
with how grades were calculated for the Physics 101 course. Because of the nature of the student body, the course stressed “hands-on” activities. These activities occurred on almost a daily basis and contributed significantly to the students’ final grades. If a student had attendance issues his or her final grade would reflect it. Without the ability to control for this and other factors it is not possible to entirely rule out a relation between final grade and these misconceptions.

The questionnaire sheets were also analyzed with regard to correctly demonstrated concepts. The first concept analyzed for the light question was whether light travels in straight lines. The vast majority of students (roughly 85%) were able to sufficiently express this concept. On the other hand, less than half of students were able to demonstrate the law of reflection. Many students did not correctly exhibit this concept because they did not believe any light rays reflected for the given circumstances and thus did not attempt to draw a reflected ray. Roughly one third of the class was able to demonstrate Snell’s law of refraction. The students that did not demonstrate this concept generally drew the light ray as a continuous straight line over the light-glass
interface. The last conception analyzed for the light question is very similar in nature to the misconception concerning the means by which an object appears a certain color. In order to correctly demonstrate the conception labeled “seeing” the student had to draw the correct light ray leaving the object either through reflection or transmission in order to ultimately reach the eye. Slightly more than half of the students were able to correctly demonstrate this concept.

As was expected, the students most consistently demonstrated the concept that was perhaps obvious, light travels in straight lines. The concepts that require more insight, or perhaps explanation, were markedly lower in demonstration frequency. Most students correctly demonstrated one or two concepts for this question.

The correctness of each questionnaire was also analyzed. The criteria for correctness did not solely depend upon the student’s representation of micro-phenomena. If the student’s statements were correct he or she would score high on the scale, even if they were only addressing macro-scale phenomena. On the three-tiered scale the students were rather evenly distributed with the
least amount in the “2” category correlating to “almost completely correct.” In general, the students scoring in the highest category described macro-scale interactions.

An investigation was undertaken to determine if exposure to high school physics would have any significant effect on any of the prior analyses. When the appropriate statistical analyses were performed it was discovered that high school physics exposure had no statistically significant effect on final course grade, epistemological representation, conceptions demonstrated, or correctness. It was determined however that students with high school physics had a statistically significant lower amount of the analyzed misconceptions per student on average.

The light question differed from the other two questions in that it was distributed in three slightly different forms. This was done in order to permit an analysis of the effect of question context on student answers. While there were some very interesting results, a formal analysis was deemed inappropriate due to the lack of clarity in student drawings.
**Light question conclusion.** Some general statements can be made concerning student performance on the light question. Many students failed to distinguish between micro and macro interactions. As discussed in Chapter 5 this is possibly the result of confusion on the students’ part, however, it may be indicative of their thinking on light and matter interactions. This argument was strengthened by the fact that students properly addressed micro scale phenomenon in the other two questions and that during the light question testing period the principle instructor verbally explained what was expected. Thus it appeared that students generally did not consider structures of a molecular scale when thinking of light-matter interactions. This may have been the result of students viewing light as an ethereal entity unable to interact with material objects.

When drawing light rays that were absorbed, the students almost always ended the ray on the air-glass interface, not drawing the ray penetrating to any depth in the glass or wood. Interestingly, many of the students also stopped the transmitting light ray at the first air-glass interface. The ray was then continued beginning at the exit interface of glass and air. In effect, the
student indicates a belief that the light ray did not exist within the material.

The light question data showed that students did not generally perceive the interaction of light and matter to take place on an atomic scale. Very few students chose to depict any interaction between molecules and light waves, almost all chose to analyze the interaction on a macro-scale. Another general observation from this data set was that few students understood the nature of seeing. A minority of students were able to predict the correct wavelength of light leaving (either through reflection or transmission) an object and entering the human eye. The idea that an eye can only sense light waves coming from an object should be general knowledge, yet appears not to be.

The data procured through the light question can be used to improve instruction concerning light and material interaction. Students should be made to understand that the interaction of light and matter is fundamentally an atomic level interaction. The nature of this interaction is beyond the mathematical sophistication of this level student, yet they should understand that frequency, wavelength, and energy of the incident light beam combined
with atomic properties of the material, determine which colors are reflected, transmitted, or absorbed and this in turn determines the color of the object.

**Current Question Summary**

The current question (Appendix 4) was the second question distributed to the Physics 101 students. This question was specifically designed to provide insight into student conceptions concerning electrical current. In contrast to the light question, the majority of students chose to depict micro-phenomena in both their drawings and verbal descriptions.

As with the light question, the first analysis performed on the current question was a categorization scheme based upon the rubric created by Driver and her coauthors (1996). As in the case of the light question, none of the student responses were deemed to be model-based. The majority of student responses, roughly 65%, were categorized as phenomenon-based. A large minority of questionnaires (roughly 35%) were classified as relation-based. The explanation of why no students’ work was classified as model-based is the same as that concerning the light question. The criteria for model-based reasoning
was fairly strict (see Table 2.1), and the student work was generally not up to these standards. It was not believed there was confusion in understanding the nature of the question, because the students generally answered in the manner intended.

The next analysis performed on the current question data set was an analysis of student misconceptions. The most common observed misconceptions were quantified and subjected to various statistical analyses. The first misconception analyzed was the so called “clashing current” misconception. In this misconception students believed that current left each battery terminal and recombined at some location in the circuit, usually the connected appliance. Approximately 20% of the participants clearly indicated applying this misconception in their answers to the current question. A possible explanation for this misconception was that students believed that positive charges emanated from the positive terminal and negative charges emanated from the negative terminal. It is then believed that since these charges are of different sign they are attracted to each other and thus recombine at the attached appliance. This speculation was somewhat backed up by a large percentage of students with this
A misconception that has been discussed in physics education literature and also observed in this data set was the depiction of electrical current as a wavy energy phenomenon. The accepted scientific view of electrical current in a metal conducting wire is that of a general drift of numerous electrons in one direction. Students with this misconception usually drew electrical current as a sinusoidal wave, though sometimes it was represented as a triangle wave or even a non-periodic random assortment of lines. About a third of the participants demonstrated this misconception through their drawings. A possible origin of this particular misconception has to do with the phenomenon of sparks. The only visualization a student experiences concerning electricity is either the spark sometimes associated with plugging in an appliance, the spark seen when touching a metal object while statically charged, and atmospheric lightning discharges. It is possible that students believed this was what electricity looks like inside a wire carrying current.
Another misconception noted in the literature and observed in this data set regards how electrical current flows in a circuit. The accepted viewpoint is that an electric field is set up in the conducting medium at virtually the speed of light; the charged electrons are affected by this field and begin flowing almost immediately in all parts of the circuit. In contrast to this, many students believed that current began flowing out of the battery terminal and proceeded serially around the circuit. This misconception was rather widespread with 35% of the respondents clearly demonstrating it. The origin of this misconception was most likely environmental experience with water flow and the common misconception that all charge is stored within the battery.

The fourth misconception analyzed for this question was the charged wire misconception. When electrons flow in a conducting wire they do so within a surrounding matrix of positive charge. Due to this there is no net charge on the wire, it remains neutral. Many students believed that the wire was neutral when there was no current flowing; however, when there was current the wire became either positively or negatively charged. This misconception affected only a small percentage of students (roughly 8%).
but was nonetheless interesting. This misconception may stem from students believing the battery is releasing large amounts of charge into a neutral wire, thus charging it.

The last misconception analyzed for this question concerns moving positive charges. In a metal conducting wire it is electrons that are responsible for the current. Roughly 42% of the Physics 101 course believed that it was positively charged particles that were flowing in the wire. The origins of this misconception are not known, but may be related to the presence of a positive battery terminal leading many students to draw positive charges leaving that terminal.

When students having any of these misconceptions were compared to students without the misconception in terms of final course grade there was a significant difference for the charged wire misconception and the wave current representation misconception. Students holding the charged wire misconception performed better than students without the misconception in terms of final grade. This difference just reached the threshold for statistical significance so further research is required to make a definitive statement. Students with the wave current misconception
performed significantly more poorly than students without this misconception in terms of final course grade.

The questionnaire sheets were also analyzed with regard to correctly demonstrated concepts. The first concept analyzed for the current question was the discrete charge carrier conception. In order to correctly demonstrate this concept the student had to draw the charge carriers as discrete entities. About 61% of the Physics 101 students correctly demonstrated this concept. The students that were unable to correctly demonstrate this concept generally drew current flow as a wavy phenomenon.

The next concept that was analyzed was whether the student demonstrated knowledge that the wire held equal amounts of charge. As previously stated, even when a wire is carrying current it generally stays electrically neutral. Only about 22% of the participants demonstrated knowledge of this concept.

The last concept analyzed for this question was the concept of moving negatively charged particles. In order to be classified as demonstrating this concept the student had to either verbally describe or pictorially represent the movement of negative charges and their role in...
electrical current. Surprisingly only about 8% of the students were able to demonstrate this concept on the current question.

The concept most commonly demonstrated was the discrete charge carrier concept. Much fewer students were able to either demonstrate that the wire remains neutral when carrying current or that negative charges are the moving objects responsible for electrical current. Most students were able to only demonstrate one concept or none at all.

The correctness of each questionnaire was also analyzed. The criteria for correctness did not solely depend upon the student’s representation of micro-phenomena. If the student’s statements were correct they would score high on the scale, even if they were only addressing macro-scale phenomena. On the three-tiered scale the students were heavily weighted toward the incorrect portion of the scale with over half of the participants scoring a “0,” the lowest rating. The “1” and “2” categories were rather evenly distributed with approximately 20% in each. In general, the students
scoring in the highest category described macro-scale interactions.

An investigation was undertaken to determine if exposure to high school physics would have any significant effect on any of the prior analyses. When the appropriate statistical analyses were performed it was discovered that high school physics exposure had no significant effect on epistemological representation, conceptions demonstrated, misconceptions, or correctness with regards to the current question.

Current question conclusion. Some general themes were observed when analyzing the student responses to the current question. Most of the students represented the charges as polarized. In many cases there were only negative or only positive charges, however, when both charges were present the student tended to draw them as polarized. As stated in the sections on misconceptions and concepts demonstrated, students had a strong tendency to believe that current could exist in one part of the circuit and not in others. The current question was specifically designed to expose this misconception due to the three different physical locations of interest and the three
different times relative to circuit closure. Sometimes the students would correctly state that current is flowing through all parts of the circuit simultaneously, however, many would then describe current moving at vastly different speeds depending on location relative to the switch and light bulb.

From reviewing the current question data it can be observed that the students have certain beliefs about electrical current. They believed that current was some moving phenomenon within the conducting wires. None of the student respondents drew or verbally described entities external to the wire affected the current flow. Also it appears that most of the students believed that electrical current was either a direct form of energy or contained energy. The misconception that current was previously contained within the battery and released into the circuit also appeared to be widespread, and was supported by previously published studies. Very few students appeared to understand that positive and negative charges exist in equal amounts within the wire and that positive charges remain locked in position. The idea of conservation of charge was not well understood by the student participants.
Many had charge either spontaneously forming or disappearing throughout the circuit.

The implications of these findings for physics education are widespread. Teaching strategies should be modified to address these conceptual misconceptions and reasoning deficiencies. Students must understand that the number of positive and negative charges in electrical circuits is generally the same. Associated with this, all students should be aware that electrons are the entity responsible for current in metal conducting wires. The virtually simultaneous initiation of current flow throughout the circuit needs to be stressed to students. Perhaps most importantly, the idea of conservation of charge needs to be explained to and understood by students. Lastly, students should be aware of the unidirectional flow of current in a direct current circuit, as many believe that current flows in two directions and clashes somewhere in the circuit.

**Resistor Question Summary**

The resistor question (Appendix 5) was the final question distributed to students. This question was specifically designed to determine student conceptions of
electrical resistance; specifically what students thought was occurring on a micro-scale within the resistor. This question is rather difficult to answer even for people far more experienced in physics than the Physics 101 students.

As in the previous questions, the first analysis performed was a categorization based upon the scheme developed by Driver and her coauthors (1996). When this was done none of the questionnaire sheets were categorized as model-based. The explanation for this was the same as for the previous questions; the students did not have a fundamental understanding of the nature of scientific inquiry. Almost exactly the same numbers of students were classified in each of the other two categories. When the quality of student responses as judged by Driver’s criteria was analyzed versus final course grade, a association was noted. Students with a higher rating on Driver’s categorization scheme performed in a superior manner compared to students with a lower rating on Driver’s scheme.

The next analysis performed concerned student misconceptions. Three misconceptions were chosen to be analyzed. The first is the so called “variable speed
misconception.” Students with this misconception believed that the current would slow drastically down upon entering a resistor and then speed back up upon exiting. The accepted view is that the current is the same throughout all aspects of the circuit. This misconception was rather common with almost 40% of the participants indicating it. This misconception may be the result of students incorporating the progressive flow model of electricity.

The second misconception analyzed was called the variable current misconception. Students retaining this misconception believed that charge will build up significantly in certain portions of the circuit. Most students with this misconception believed there would be excess charge build up on the positive side of the resistor. About 17% of the class clearly demonstrated this misconception in their work. It is very possible that this misconception was the result of thinking about electrical resistance through the “traffic flow” analogy. This would then be a case of students applying an analogy outside its scope of effectiveness.

The final misconception is an interesting one and not found in previous literature. A minority of students
(roughly 22%) believed that there exists a concentration of charge on the external surface, or in the space around a resistor. The origin of this misconception remains obscure and it is an interesting topic for further research.

The next analysis performed involved the concepts correctly demonstrated by the students. The first concept analyzed was the negative discreet charge carrier model. This was very similar to an analysis performed for the current question; this was done purposely in order to allow comparison between the two questions. For this question 32% of the respondents correctly predicted the existence of discreet negatively charged objects acting as the current agent. This was roughly half the number of students demonstrating the same concept on the current question. The existence of the resistor in the circuit contributed to a major decrease in student ability to correctly determine the current carrying agent.

The second concept analyzed was the relationship between resistance and current. Through Ohm’s law it is known that in a simple direct current circuit the current is inversely proportional with the resistance. Only about
21% of the Physics 101 students were able to correctly demonstrate this concept on their question sheets.

The correctness of each questionnaire was also analyzed. The criteria for correctness did not solely depend upon the student’s representation of micro-phenomena. If the student’s statements were correct they would score high on the scale, even if they were only addressing macro-scale phenomena. On the three-tiered scale the students were heavily weighted into the “0,” or most incorrect category, with approximately 80% categorized as such. The middle category had virtually the rest of the participants, with the highest level of correctness only applying to three questionnaires. These results were much more biased toward the incorrect end of the scale than the other two questions. It is believed this was because of the difficult subject matter and less student experience with the concept of resistance.

An investigation was undertaken to determine if exposure to high school physics would have any significant effect on any of the prior analyses. When the appropriate statistical analysis was performed it was discovered that high school physics exposure had no significant effect on
epistemological representation, conceptions demonstrated, misconceptions, or correctness with regards to the resistor question.

**Resistor question conclusion.** When analyzing the resistor question certain student conceptions continually arose. Many of the students associated electrical resistance with the speed of the charge carrying particles. This was the primary theme of the resistor question. Many of the students also predicted that charge would travel through the resistor in a narrow band, similar in width to the connecting wire. They did not predict charge carriers in the extremities of the resistor body. Unlike in the current question, many of the students predicted external charges or fields when the resistor was added to the circuit.

It appears that students had a general understanding that resistance affects current in a circuit. However, the nature of this effect differed between students. Some indicated that increased resistance will lead to greater current levels; others indicated that there is an inverse relation between current and resistance. Some students indicated that resistors affect the number of charge
carriers permitted, others indicated that resistors affected the speed of the charge carriers. The largest variation in student opinion concerned the mechanism by which a resistor influenced current. The answers for this ranged from accumulated charge within the resistor to external force fields surrounding the resistor.

Information gained from the resistor question can be used to improve instructional techniques. The most important concept for students to understand is that resistance and current are inversely proportional. Such an intuitive understanding of Ohm’s law is imperative for students to obtain. Also the idea that a resistor accumulates charge and that is what slows current should be dispelled. A true explanation of resistance in a carbon resistor is not possible for this level student; however they should be made aware that the resistance is dependent on the type of material used. Students should also be made aware that resistors do not create resistance by external charges or fields, only by the electrical properties of the material contained within the body of the resistor.
Implications

Though this study only analyzed three different questions in one subtopic of physics education some general statements may be inferred from the data. One conclusion that is difficult not to draw is the general ineffectiveness of high school physics courses in preparing students for physics at the university level. The data generated for this project generally demonstrated no significant difference in performance, as measured both conventionally (i.e. final course grade) and by the metrics specifically used in this project, between students with exposure to high school physics and students without. The inference is that students’ are not maintaining the physics knowledge they learn in high school and generally begin their college physics course on equal footing with students whom did not take high school physics.

How can this apparent ineffectiveness of high school physics be overcome? There are many different approaches and attitudes toward how physics should be taught at the high school level. It is the opinion of this researcher that at least part of the problem lies in the amount of material covered during a conventional high school physics
course. The majority of high school physics courses strive to cover all of physics (i.e. the entire textbook) in one year. Cognitive research has shown that the amount of new material presented in such a class is more than a typical person can process or learn (Wieman & Perkins, 2005). Before a student can truly understand a topic it is already time to move onto a new one.

The simple solution to this problem is to reduce the amount of material covered during a high school physics course and concentrate on the fundamentals. This idea has been attacked by some whom believe it is very important to introduce students to a wide variety of material. However, if one year later the student retains little to none of the information, such an approach seems counterproductive. In addition, it may be beneficial to stress conceptual understanding in lieu of mechanically working problems. Physics is a very dynamic, creative field and should not be reduced to simply “plugging and chugging” numbers into equations.

As thoroughly discussed in Chapter 1 it is imperative that future generations have a fundamental understanding of science in order to function effectively as engaged
citizens. What this project has helped to confirm is that simply taking a science course does not lead to scientific literacy. The students in this research project, all of whom had been exposed to science courses of some type, demonstrated significant trouble with the nature of scientific theories as demonstrated by the epistemological representation analysis.

In order to be considered scientifically literate in the 21st century one must have a basic understanding of important issues such as the processes behind global warming, energy consumption and generation, pollution, genetic research and its applications, along with many others. Though these topics are very complex, they can be fundamentally understood utilizing only basic principles of science.

Of course people entering scientific fields need to be trained intensively on the minute details of their field. However many students enrolled in science courses are not on this type of career path and may not benefit from the teaching approaches used in the past. If basic ideas are expressed and reinforced throughout the course it is
expected that student knowledge retention rate for these large ideas would be relatively good.

**Suggestions for Future Research**

The nature of this research project was to explore an area of physics education research that has been somewhat neglected. Because many of the approaches used for this project had not been previously incorporated by researchers there was much to be learned. Thus by its very nature this project generated numerous ideas for future research, both in improvements to techniques employed in this project and in entirely different approaches to student conceptions.

The categorization scheme of Driver (1996) was applied strictly for this research project. This resulted in no students’ responses being classified as model-based. Even though none reached the standards proposed by Driver, there were many that met at least some of the standards. If Driver’s criteria were somewhat relaxed and slightly modified, a more fine differentiation between levels of student work could have been achieved.

A modified version of this study could possibly answer some of the questions raised concerning student reasoning
and intentions. If done on a smaller scale than the 130 respondents for this project, an investigator could perform in person interviews with the students to more clearly define their intentions. This type of project may be less generalizable due to its smaller sample size, but it would be more detailed in its qualitative explanations. A similar study to this one but performed with different types of students would possibly shed light on any specific issues with female or elementary education majors. It is predicted that many of the same misconceptions would appear with students from more technical fields.

For the light question multiple forms were distributed in hopes of determining the effect of context on students’ responses. As has been discussed previously a rigorous statistical analysis of this data was not feasible. However, the nature of student responses in varying contexts is a very promising area of research. In order to properly address this subject, the forms must be differentiated more than they were for the light question. Simply drawing the schematic larger likely would have helped immensely in analysis potential. Multiple questions could be employed, each with multiple versions. This would give the investigator flexibility in analytical techniques
that was unavailable for this project since only one question used multiple versions.

It may also be interesting to ask a similar question to the light question but without explicitly telling the student that red, green, and blue light are incident. Instead it can just be “sunlight” or “white light,” the way students depict individual colors interacting may be interesting.

When the same concept was analyzed in the current question and the resistor question vastly different results were found. An interesting idea would be to combine these two questions into one. If students had to draw what was happening inside the wire in multiple locations within a circuit containing a resistor would they revert to using discreet charges as in the current question or the energy wave representation more common for the resistor question. Also would the students suggest external charges and fields around the resistor or state that all charges are internal.

A potentially interesting project would be to ask the same questions used in this project to two groups of students. The first group would be students that had taken a high school physics course that covered few topics but
very thoroughly. The second group would be students that had taken a more traditional fast-paced high school course. The contrasting results would provide some insight into the relative effectiveness of both methods.

In general more research needs to be performed on the underrepresented demographic groups analyzed in the research project. It is only through an increased understanding of how all types of students construct knowledge of the physical world will the instruction of students in physics reach the level necessary for a robust scientifically literate citizenry.
REFERENCES


Chu, H., Treagust, D., & Chandrasegaran, A. (2007). Naïve students’ conceptual development and beliefs: The need for multiple analyses to determine what contributes to
student success in a university introductory physics course. Springer Science.


374


Title: How do pre-service teachers picture various electromagnetic phenomenon? A qualitative study of pre-service teachers' conceptual understanding of fundamental electromagnetic interaction.

Script:
Hello, my name is Christopher Beer and I am a 4th year doctoral student in the Department of Physics and Astronomy. I am currently working with Dr. Joel Bryan on my doctoral dissertation titled, “How do pre-service teachers picture various electromagnetic phenomenon? A qualitative study of pre-service teachers' conceptual understanding of fundamental electromagnetic interaction.” This research will be used to help improve physics instruction at the introductory level for future students.

If you volunteer as a participant in this study, several of your assignments dealing with electromagnetism will be analyzed to discern the nature of your conceptions. These assignments are a standard part of the PHYCS 101 course and will take approximately 15 minutes each. If you do not choose to participate you will still need to complete the assignments, however, your responses will not be included in the analysis.

I would like to assure you that this study has been reviewed and received ethics clearance through the Sponsored Programs Office of Ball State University. However, the final decision about participating is yours.

If you are interested in participating please sign the consent form and return it to me.

Thank you
APPENDIX 2
Student Information (Please Print)

Name: ______________________________________________________________________

Age: _______ Male – Female       E-mail: ________________________________

Hometown: ____________________ High School: _______________________________

BSU Classification: ___________________

Degree Sought/Teaching Specialization: ________________________________

What courses, grades, or subjects are you most interested in teaching?

Please list all science and math courses that you completed in high school and those you have completed and/or are now taking at the university level. Place an asterisk (*) next to any course in which you are currently enrolled.

<table>
<thead>
<tr>
<th>High School</th>
<th>University</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Math Courses</strong></td>
<td><strong>Science Courses</strong></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Briefly describe your past experiences/feelings as a science student.

Briefly describe some of your other interests/activities/jobs/family, etc….

What are your thoughts/feelings about the prospect of you one day teaching physics and/or other science concepts to elementary or special education students?

On the back of this page, please share with me any other information you think that would be helpful for me to know about you.
APPENDIX 3

How do you picture the transmission, reflection, and absorption of light?

When white light, comprised of the entire rainbow spectrum of colors, travels through air and shines on any material, a portion of the light's energy may be reflected, a portion may be transmitted, and a portion may be absorbed. For each case below, draw and label a diagram that illustrates how/why portions of the incident light's energy may be transmitted, reflected, and absorbed by each of these materials. In addition to your illustration, make a statement that explains why each color exhibited the behaviors you illustrated.

Case 1: Illustrate what happens when red, green, and blue light travels through air and reaches transparent colorless glass.

Written explanation:

Case 2: Illustrate what happens when red, green, and blue light travels through air and reaches transparent blue glass.

Written explanation:

Case 3: Illustrate what happens when red, green, and blue light travels through air and reaches a piece of blue-painted wood.

Written explanation:
How do you picture the transmission, reflection, and absorption of light?

When white light, comprised of the entire rainbow spectrum of colors, travels through air and shines on any material, a portion of the light's energy may be reflected, a portion may be transmitted, and a portion may be absorbed. For each case below, draw and label a diagram that illustrates how/why portions of the incident light's energy may be transmitted, reflected, and absorbed by each of these materials. In addition to your illustration, make a statement that explains why each color exhibited the behaviors you illustrated.

Case 1: Illustrate what happens when red, green, and blue light travels through air and reaches transparent colorless glass.

Written explanation:

Case 2: Illustrate what happens when red, green, and blue light travels through air and reaches transparent blue glass.

Written explanation:

Case 3: Illustrate what happens when red, green, and blue light travels through air and reaches a piece of blue-painted wood.

Written explanation:
How do you picture the transmission, reflection, and absorption of light?

When white light, comprised of the entire rainbow spectrum of colors, travels through air and shines on any material, a portion of the light’s energy may be reflected, a portion may be transmitted, and a portion may be absorbed. For each case below, draw and label a diagram that illustrates how/why portions of the incident light’s energy may be transmitted, reflected, and absorbed by each of these materials. In addition to your illustration, make a statement that explains why each color exhibited the behaviors you illustrated.

Case 1: Illustrate what happens when red, green, and blue light travels through air and reaches transparent colorless glass.

```
x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x
```

← transparent, colorless glass

“X” represents molecules

Written explanation:

Case 2: Illustrate what happens when red, green, and blue light travels through air and reaches transparent blue glass.

```
x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x
```

← transparent blue glass

Written explanation:

Case 3: Illustrate what happens when red, green, and blue light travels through air and reaches a piece of blue-painted wood.

```
x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x     x
```

← opaque wood, painted blue

“X” represents molecules

Written explanation:
How do you picture electrical current in a simple circuit?

You are aware that simple circuits contain electrical currents in certain situations. For each case below, **draw and label a diagram that illustrates** what is physically occurring inside the wire. In addition to your illustration, make a statement that explains why you think this is occurring inside the wire.

1.) While the switch is open (off position): Explain your diagrams

   A:  
   B:  
   C:  

2.) Immediately after the switch is closed: Explain your diagrams

   A:  
   B:  
   C:  

3.) 30 Seconds after the switch is closed (on position): Explain your diagrams

   A:  
   B:  
   C:  

You are aware that simple circuits contain electrical currents in certain situations. For each case below, **draw and label a diagram that illustrates** what is physically occurring inside the wire. In addition to your illustration, make a statement that explains why you think this is occurring inside the wire.
APPENDIX 5

How do you picture electrical current in a resistor?

You are aware that simple circuits contain electrical devices known as resistors. For each case below, **draw and label a diagram that ILLUSTRATES** what is physically occurring inside the resistor. In addition to your illustration, make a statement that explains why you think this is occurring inside the resistor.

*Illustrate what is happening inside the different resistors for the complete circuit with a 10V battery.*

1 Ohm

2 Ohm

10 Ohm

**Written Explanation:**

**Written Explanation:**

**Written Explanation:**
Study Title  How do pre-service teachers picture various electromagnetic phenomenon? A qualitative study of pre-service teachers’ conceptual understanding of fundamental electromagnetic interaction.

Study Purpose and Rationale
The purpose of this research project is to analyze how pre-service teachers conceptualize various electromagnetic phenomenon. It is hoped that a better understanding of this process will allow instructors to improve course material presentation and student understanding.

Inclusion/Exclusion Criteria
To be eligible to participate in this study, you must be at least 18 years of age and enrolled in PHYCS 101 during spring semester 2009 – 2010.

Participation Procedures and Duration
For this project, you will be asked to complete a series of questionnaires about electromagnetic phenomenon. These questionnaires are included as part of the standard course work. It will take approximately 15 minutes to complete each questionnaire.

Audio or Video Tapes
There will be no audio or video taping associated with this research project.

Disclosure of Alternative Procedures
There are no alternative procedures for these questionnaires because they are a standard part of the PHYCS 101 course, however, if you do not sign the consent form your responses will not be included in the research project.

Data Confidentiality or Anonymity
All data will be maintained as confidential and no identifying information such as names will appear in any publication or presentation of the data.

Storage of Data
Paper data will be stored in a locked filing cabinet in the researcher’s office for 10 months and will then be shredded. The data will also be entered into a software program and stored on the researcher’s password-protected computer for 10 months and will then be securely deleted. Only the principle investigator will have access to the data.

Risks or Discomforts
There are no anticipated risks or discomforts associated with participating in this research project.

Benefits
The results generated from this research project will be used to increase the effectiveness of introductory physics education for future university students.

Voluntary Participation

Your participation in this study is completely voluntary and you are free to withdraw your permission at anytime for any reason without penalty or prejudice from the investigator. Please feel free to ask any questions of the investigator before signing this form and at any time during the study.

IRB Contact Information

For one’s rights as a research subject, you may contact the following: Research Compliance, Sponsored Programs Office, Ball State University, Muncie, IN 47306, (765) 285-5070, irb@bsu.edu.

Study Title  How do pre-service teachers picture various electromagnetic phenomenon? A qualitative study of pre-service teachers' conceptual understanding of fundamental electromagnetic interaction.

*********

Consent

I, ______________________, agree to participate in this research project entitled, “How do pre-service teachers picture various electromagnetic phenomenon? A qualitative study of pre-service teachers' conceptual understanding of fundamental electromagnetic interaction.” I have had the study explained to me and my questions have been answered to my satisfaction. I have read the description of this project and give my consent to participate. I understand that I will receive a copy of this informed consent form to keep for future reference.

To the best of my knowledge, I meet the inclusion/exclusion criteria for participation (described on the previous page) in this study.

________________________________            ______________________
Participant’s Signature                  Date

Researcher Contact Information

Principal Investigator:                Faculty Supervisor:
Christopher Beer, M.S.                Dr. Joel Bryan
Physics and Astronomy                Physics and Astronomy
Ball State University                 Ball State University
Meeting Times/Location:

Lecture: (Section 001);
1:00 – 1:50 PM (Section 002)

Laboratory: CP 102
Lab Section 001: Monday 10:00 AM – 12:00 PM
Lab Section 002: Monday 12:00 PM – 2:00 PM
Lab Section 003: Friday 10:00 AM – 12:00 PM
Lab Section 004: Friday 12:00 PM – 2:00 PM

Course Instructors:

Joel A. Bryan, Ph.D. CP 101G; office hours daily by appointment
Phone: office (765) 285-4718 E-mail: jabryan@bsu.edu

Chris Beer CP 132; office hours Tuesday, Wednesday, Thursday by appointment
Phone: office (765) 285-8882 E-mail: cpbeer@bsu.edu
Textbooks:

Recommended: **Conceptual Physics**, 10th ed., Paul G. Hewitt (Addison-Wesley)

Physics Classroom Tutorial (free web resource)

Useful Links:

- [http://jabryan.iweb.bsu.edu/PHYCS101_SPR2010.htm](http://jabryan.iweb.bsu.edu/PHYCS101_SPR2010.htm)  
  Web site URL for quick schedule and downloads

- [https://blackboard.bsu.edu/webapps/login/](https://blackboard.bsu.edu/webapps/login/)  
  Blackboard site for detailed description of the daily schedule/assignments/due dates and points awarded for assignments

  The purchase of the textbook enables the buyer to have free access to the textbook web site. This helpful study aid contains notes, movie clips, self-assessment questions, interactive simulations and other links correlating to each chapter in the textbook. You may also purchase web access without purchasing the textbook.

  This is an excellent tutorial and resource site for physics teaching and learning. Portions of your quizzes, homework, and exams will come directly from the practice questions linked to this resource.

- [http://www.learner.org/resources/series42.html?pop=yes&vodid=74745&pid=549](http://www.learner.org/resources/series42.html?pop=yes&vodid=74745&pid=549)  
  The Mechanical Universe video series - an excellent resource for historical physics content

- [http://www.indianastandards.org/](http://www.indianastandards.org/)  
  Indiana’s State Academic Standards - search by subject, grade level, and standard

  "Cheesy" science songs from the 20th century - Put these on your iPod! - Play them for your students! - Fun for all at the physics parties!

- [http://inqsit.bsu.edu/](http://inqsit.bsu.edu/)  
  Ball State University inQsit online test and homework system
Course Objectives:

This course is designed and recommended for preservice elementary teachers. Credit in this course may not satisfy your science requirement if you are not in a teacher certification program. Please consult your advisor if you have questions regarding if or how this course may apply toward your degree.

- Our goals are that by completing this course, you will obtain:
  - an awareness and a conceptual understanding of the physics concepts that are included in the k-6 state and national standards
  - confidence in your ability to teach/explain these concepts to others using a variety of instructional methods (e.g., lecture, demonstration, discovery, computer simulations, etc...)
  - an awareness of “hands-on” laboratory activities, including those classified as "inquiry", that could be used to teach/explain these concepts to others
  - an awareness of how computer technology may be used in teaching/explaining these physics concepts to others
  - a better understanding of how instructional materials are used by students when learning physics concepts
  - a basic understanding of commonly accepted attributes of the “nature of science” and the limitations of science

These goals reflect the desire that you gain experience in investigating physics topics that you may encounter when you become a classroom teacher. As such, it is understandable that you may not obtain a "deep understanding" of these topics in just one semester of study. As a result, the major portion of your course grade is dependent upon your active participation in these experiences, rather than performance on assessment instruments (i.e., major exams).

Attendance:

You are expected to attend ALL class sessions and arrive ON TIME. Points may be subtracted from group laboratory reports if you arrive late and/or leave early. You should bring a calculator to all class and laboratory sessions. You will be notified in advance when you will need your laptop computer. Be sure to regularly check the schedule below and check your Ball State email account for instructor messages.

The majority of the work counting toward your point total and final grade will be performed in class and/or lab meetings. Much of it will be “group work” that would be inconvenient, if not impossible, to make up as an individual.
** Perfect or near perfect attendance is the best way to ensure success in this course **

PLEASE RESPECT YOUR CLASSMATES AND INSTRUCTOR BY SILENCING ALL ELECTRONIC DEVICES DURING CLASS AND LAB MEETINGS, AND LIMIT COMPUTER USE TO CLASS-RELATED ACTIVITIES. NO ELECTRONIC DEVICES ARE PERMITTED DURING QUIZZES AND EXAMS, OR AT OTHER TIMES AS DIRECTED BY THE INSTRUCTOR.
Grading:

Your grade in this course will be based on the total points you obtain in relation to the total points available on all work.

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
</table>
| LABORATORY AND CLASS WORK | • A mixture of “hands-on” and computer simulated data collection and exploration group and individual activities serving to aid in the development and/or understanding of physics concepts  
                     • Worksheets and other group activities  
                     • Laboratory activities and investigations will also take place during the Tuesday and Thursday “lecture” sessions. |
| INQSIT QUESTION SETS | • Multiple choice questions posted weekly on inQsit. See Blackboard's detailed daily schedule for the strictly enforced due dates. These 20 questions serve as a review of class/laboratory activities and concepts and as preparation for the major exams and quizzes. You will have three opportunities to take each of these inQsit question sets. The best score is the one that counts. |
| QUIZZES/EXAMS     | • Short answer quizzes worth 10 points each will be given periodically during the lecture or laboratory sessions in order to encourage attendance and assess your understanding of the concepts covered during the semester  
                     • Three 100-point exams will be given on inQsit - see schedule for exact dates. Each of these exams will have 10 "bonus" points available. |

Your course grade will be determined by the total number of points you earned during the semester in relation to the total number of points that were available. The table below gives points percentages needed for each grade. These values may be “relaxed” at the discretion of the instructor after careful examination of the final distribution of student point totals.

<table>
<thead>
<tr>
<th>Course Grade</th>
<th>% Points Received</th>
<th>Points Needed (based on 1140 possible)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>87.5% - 100%</td>
<td>998</td>
</tr>
<tr>
<td>A-</td>
<td>84.5% - 87.5%</td>
<td>963</td>
</tr>
<tr>
<td>B+</td>
<td>81.5% - 84.5%</td>
<td>929</td>
</tr>
<tr>
<td>Grade</td>
<td>Percentage Range</td>
<td>Total</td>
</tr>
<tr>
<td>-------</td>
<td>------------------</td>
<td>-------</td>
</tr>
<tr>
<td>B</td>
<td>75.5% - 81.5%</td>
<td>861</td>
</tr>
<tr>
<td>B-</td>
<td>72.5% - 75.5%</td>
<td>827</td>
</tr>
<tr>
<td>C+</td>
<td>69.5% - 72.5%</td>
<td>792</td>
</tr>
<tr>
<td>C</td>
<td>63.5% - 69.5%</td>
<td>724</td>
</tr>
<tr>
<td>C-</td>
<td>60.5% - 63.5%</td>
<td>690</td>
</tr>
<tr>
<td>D+</td>
<td>57.5% - 60.5%</td>
<td>656</td>
</tr>
<tr>
<td>D</td>
<td>51.5% - 57.5%</td>
<td>587</td>
</tr>
<tr>
<td>D-</td>
<td>48.5% - 51.5%</td>
<td>553</td>
</tr>
<tr>
<td>F</td>
<td>&lt; 48.5%</td>
<td>&lt; 553</td>
</tr>
</tbody>
</table>

**Make-up Policy:**

Rather than dropping any specified number of inQsit question sets, homework, class work, and/or laboratory grades, the grading scale described above 1) allows each student to miss several graded activities without detrimental effects on the final grade, and 2) rewards those who rarely miss class by giving them ample opportunities to earn extra points that could make up for a few low grades and/or poor exam scores. Effectively, every one of you has the opportunity to earn "extra" points to make up for missed points or low scores on assignments, as any 4-5 labs or other graded activities can be considered bonus activities which will serve as make up for missed activities or extra points to add to your total.

Because this grading system is designed to encourage you to attend as many class and laboratory sessions as possible, and reward those with excellent attendance without penalizing those who have a modest number of absences, there will be NO MAKE UP WORK ALLOWED, except for rare special situations determined at the discretion of the instructors.
Schedule/Topics of Study:

Physics topics chosen for this course reflect content areas that are included in state and national standards for k-6 grade. You are responsible for downloading and printing your own copies of laboratory instructions, class notes, homework assignments, and any other documents linked to this chart. Please check this table regularly for updates/changes. See Blackboard for a more detailed description of assignments and due dates.

<table>
<thead>
<tr>
<th>Date</th>
<th>Topic</th>
<th>Physics Classroom/Tutorial Links</th>
<th>Activities &amp; Downloads</th>
<th>Points Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tu</td>
<td>1/12</td>
<td>Class Policies; Science, Physics Defined</td>
<td>VARK</td>
<td>10</td>
</tr>
<tr>
<td>Tr</td>
<td>1/14</td>
<td>Recording Measured Quantities</td>
<td>Measurement Slideshow; Precision of Laboratory Measurements &amp; Extension Letter</td>
<td>10+10</td>
</tr>
<tr>
<td>F/M</td>
<td>1/15,18</td>
<td>No Labs meet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tu</td>
<td>1/19</td>
<td>Constant Velocity (Speed)</td>
<td>Link</td>
<td>10</td>
</tr>
<tr>
<td>Th</td>
<td>1/21</td>
<td>Relative Velocity (Speed)</td>
<td>Link</td>
<td>10</td>
</tr>
</tbody>
</table>

**InQsit Question Set 1 - posted Wednesday, Jan 20 - due midnight Monday, Jan 25**

| F/ | 1/22 | Lab Session #1 | Link | Acceleration Down an | 20 |

393
<table>
<thead>
<tr>
<th>M</th>
<th>5</th>
<th>- Accelerated Motion</th>
<th>Incline; Excel Graphing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tu</td>
<td>1/26</td>
<td>Acceleration of Gravity</td>
<td>Link; Freefall Simulation</td>
</tr>
<tr>
<td>Tr</td>
<td>1/28</td>
<td>Falling Objects</td>
<td>Link; Quiz 1</td>
</tr>
</tbody>
</table>

InQsit Question Set 2 - posted Wednesday, Jan 27 - due midnight Monday, Feb 1

<table>
<thead>
<tr>
<th>F/M</th>
<th>1/29;2/1</th>
<th>Lab Session #2 - Inertia, Mass, and Weight</th>
<th>Link; Inertia, Mass, &amp; Weight; Newton's Laws Slideshow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tu</td>
<td>2/2</td>
<td>Newton's 1st Law of Motion</td>
<td>Link; 1st Law</td>
</tr>
<tr>
<td>Th</td>
<td>2/4</td>
<td>Newton's 2nd Law of Motion</td>
<td>Link; 2nd Law</td>
</tr>
</tbody>
</table>

InQsit Question Set 3 - posted Wednesday, Feb 3 - due midnight Monday, Feb 8

<table>
<thead>
<tr>
<th>F/M</th>
<th>2/5,8</th>
<th>Lab Session #3 - Periodic Motion</th>
<th>Mass on a Spring; Pendulum (lab sheet provided in class)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tu</td>
<td>2/9</td>
<td>Newton's 3rd Law of Motion</td>
<td>Link; 3rd Law</td>
</tr>
<tr>
<td>Tr</td>
<td>2/11</td>
<td>Constant and Accelerated Motion Summary</td>
<td>Quiz 2</td>
</tr>
</tbody>
</table>

InQsit Question Set 4 - posted Wednesday, Feb 10 - due midnight Monday, Feb 15

| F/M   | 2/12,15 | Lab Session #4 - Wave Modeling | Link; Waves Slideshow; Wave Modeling; Pulses on a Coil Spring |

Exam 1 - Take week of February 15 - 19: ABSOLUTE DEADLINE is Friday, February 19, at 8:00 PM - NO EXCEPTIONS!!

| Tu    | 2/16    | Wave Properties | Link; Ripple Tank Simulation |
| Th    | 2/18    | Standing Waves  | Link; Standing Waves |

InQsit Question Set 5 - posted Wednesday, Feb 17 - due midnight Monday, Feb 22

<table>
<thead>
<tr>
<th>F/M</th>
<th>2/19,22</th>
<th>Lab Session #5 - Sound and Music</th>
<th>Link; Sound and Music; Sound Slideshow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tu</td>
<td>2/23</td>
<td>Sound and Music</td>
<td>Link; Resonance: Speed of</td>
</tr>
</tbody>
</table>

394
<table>
<thead>
<tr>
<th>Day</th>
<th>Date</th>
<th>Activity Description</th>
<th>Link</th>
<th>Quiz/Investigations</th>
<th>Credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tr</td>
<td>2/25</td>
<td>Resonance Sound Characteristics and Properties</td>
<td>Link</td>
<td>Palm Pipes; Quiz 3</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>InQsit Question Set 6 - posted Wednesday, Feb 24 - due midnight Monday, March 1</td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>F/M</td>
<td>2/26;3/1</td>
<td>Lab Session #6 - Reflection</td>
<td>Link</td>
<td>Reflection Slideshow; Plane Mirror Reflection</td>
<td>20</td>
</tr>
<tr>
<td>Tu</td>
<td>3/2</td>
<td>Reflection in Full Length Mirrors</td>
<td>Link</td>
<td>Full Length Mirrors (activity sheet provided in class)</td>
<td>10</td>
</tr>
<tr>
<td>Th</td>
<td>3/4</td>
<td>Curved Mirrors</td>
<td>Link</td>
<td>Curved Mirrors</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>InQsit Question Set 7 - posted Wednesday, March 3 - due midnight Monday, March 15</td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>F/M</td>
<td>3/5,15</td>
<td>Lab Session #7 - Refraction</td>
<td>Link</td>
<td>Refraction Investigations; Refraction Slideshow</td>
<td>20</td>
</tr>
<tr>
<td>Tu</td>
<td>3/16</td>
<td>Converging Lenses</td>
<td>Link</td>
<td>Images in Converging Lenses</td>
<td>10</td>
</tr>
<tr>
<td>Tr</td>
<td>3/18</td>
<td>Lenses</td>
<td>Link</td>
<td>Quiz 4</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>InQsit Question Set 8 - posted Wednesday, March 17 - due midnight Monday, March 22</td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>F/M</td>
<td>3/19,22</td>
<td>Lab Session #8 - Color Mixing</td>
<td>Link</td>
<td>Color Slideshow; Light and Color Mixing</td>
<td>20</td>
</tr>
<tr>
<td>Tu</td>
<td>3/23</td>
<td>Diffraction and Interference</td>
<td>Link</td>
<td>Diffraction/Interference Slideshow; Double Slit Interference</td>
<td>10</td>
</tr>
<tr>
<td>Th</td>
<td>3/25</td>
<td>Color Separation</td>
<td>Link</td>
<td>Spectroscopes</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>InQsit Question Set 9 - posted Wednesday, March 24 - due midnight Monday, March 29</td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>F/M</td>
<td>3/26,29</td>
<td>Lab Session #9 - Static Electricity</td>
<td>Link</td>
<td>Electricity Slideshow; Static Electricity Investigations; Periodic Table</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Exam 2 - Take week of March 29 - April 2: ABSOLUTE DEADLINE is Friday, April 2, at 8:00 PM - NO EXCEPTIONS!!</td>
<td></td>
<td></td>
<td>110</td>
</tr>
<tr>
<td>Tu</td>
<td>3/30</td>
<td>Charge &quot;Storage&quot;</td>
<td>Link</td>
<td>Leyden Jar</td>
<td>10</td>
</tr>
<tr>
<td>Tr</td>
<td>4/1</td>
<td>Static</td>
<td>Link</td>
<td>Electrophorus</td>
<td>10</td>
</tr>
<tr>
<td>Date</td>
<td>Lab Session #10 - Electrochemical Cells</td>
<td>Link</td>
<td>Voltaic Pile; Electrochemical Cells</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>----------------------------------------</td>
<td>------</td>
<td>------------------------------------</td>
<td>----</td>
<td></td>
</tr>
<tr>
<td>Tu</td>
<td>Batteries</td>
<td>Link</td>
<td>Cells in Series, Parallel, and Combination</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Th</td>
<td>Electric Potential Difference</td>
<td>Link</td>
<td>Quiz 5</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>F/ M</td>
<td>4/2,5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>Lab Session #11 - Resistor Circuits</th>
<th>Link</th>
<th>Resistance and Resistor Circuits</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tu</td>
<td>Series, Parallel, and Combination Resistor Circuits</td>
<td>Link</td>
<td>Quiz 6</td>
<td>10</td>
</tr>
<tr>
<td>Tr</td>
<td>Kirchhoff's Circuit Laws</td>
<td>Link</td>
<td>Kirchhoff's Circuit Laws</td>
<td>10</td>
</tr>
<tr>
<td>F/ M</td>
<td>4/9,12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>Lab Session #12 - Light Bulb Circuits</th>
<th>Link</th>
<th>Light Bulb Circuits</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tu</td>
<td>Resistor Circuits</td>
<td>Link</td>
<td>Resistor Circuits Worksheet</td>
<td>10</td>
</tr>
<tr>
<td>Th</td>
<td>DC Circuits Summary</td>
<td>Link</td>
<td>Quiz 7</td>
<td>10</td>
</tr>
<tr>
<td>F/ M</td>
<td>4/16,19</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>Lab Session #13 - Electromagnetism</th>
<th>Link</th>
<th>Magnetism Slideshow; Electromagnetism</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tu</td>
<td>Electromagnetic Induction</td>
<td>Link</td>
<td>Making Electricity</td>
<td>10</td>
</tr>
<tr>
<td>Tr</td>
<td>Electromagnetic Phenomena</td>
<td>Link</td>
<td>End of Course Evaluations</td>
<td></td>
</tr>
<tr>
<td>F/ M</td>
<td>4/23,26</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

InQsit Question Set 10 - posted Wednesday, March 31 - due midnight Monday, April 5

InQsit Question Set 11 - posted Wednesday, April 7 - due midnight Monday, April 12

InQsit Question Set 12 - posted Wednesday, April 14 - due midnight Monday, April 19

InQsit Question Set 13 - posted Wednesday April 21 - due midnight, Monday April 26
University Policies:

Policy on Scholastic Dishonesty: Students who violate university rules on scholastic dishonesty are subject to disciplinary penalties, including the possibility of failure in the course and/or dismissal from The University. Since such dishonesty harms the individual, all students, and the integrity of The University, policies on scholastic dishonesty will be strictly enforced. Please refer the Code of Student Rights and Responsibilities at [http://www.bsu.edu/sa/article/0,1375,207455-14207-48112,00.html](http://www.bsu.edu/sa/article/0,1375,207455-14207-48112,00.html) for more information.

Americans With Disabilities Act: The American With Disabilities Act (ADA) is a federal anti-discrimination statute that provides comprehensive civil rights protection for persons with disabilities. Among other things, this legislation requires that all class members with disabilities be guaranteed a learning environment that provides for reasonable accommodation of their disabilities. If you need course adaptations or accommodations because of a disability, if you
have emergency medical information to share with me, or if you need special arrangements in case the building must be evacuated, please make an appointment with me as soon as possible. If you request an accommodation, you need to provide me with a letter from Richard Harris whose office is located in the Student Center #307, (phone): 285-5293.