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Investigating The Impact Of Visuohaptic Simulations For Conceptual Understanding In Electricity And Magnetism

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Graduate School ETD Form 9
(Revised 12/07)

PURDUE UNIVERSITY
GRADUATE SCHOOL
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By KARLA L. SANCHEZ MARTINEZ

Entitled
INVESTIGATING THE IMPACT OF VISUOHAPTIC SIMULATIONS FOR CONCEPTUAL UNDERSTANDING IN ELECTRICITY AND MAGNETISM

For the degree of Master of Science

Is approved by the final examining committee:

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Head of the Graduate Program Date

INVESTIGATING THE IMPACT OF VISUOHAPTIC SIMULATIONS FOR CONCEPTUAL UNDERSTANDING IN ELECTRICITY AND MAGNETISM

A Thesis

Submitted to the Faculty

of

Purdue University

by

Karla L. Sanchez Martinez

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science

December 2013

Purdue University

West Lafayette, Indiana

To my husband Igor, for his unconditional love and support all these years.

Gracias por todo tu amor, apoyo y cariño.

Te amo mi amor.

A mis queridos padres, hermanas y familia, gracias por estar siempre ahí apoyándome y creyendo en mí.

Los amo.

ACKNOWLEDGEMENTS

I would like to start by expressing my gratitude to my advisor Professor Alejandra J. Magana for giving me the opportunity to work with her and learn from her. I am deeply grateful for all of her guidance and support. Likewise, I would like to thank Professor Bedrich Benes and Professor Grant P. Richards for serving on my defense committee and for their help and advice throughout my time at Purdue. Finally, I would also like to thank Professor David Sederberg, Professor Gail Jones and Professor Hong Tan for their valuable comments and support in the present research project.

In addition, I would like to thank all my friends and colleagues at Purdue University for their friendship. Thank you Romina, Camilo, Rosario, Junchao, Tosin, O hyun, Ryan, Manaz, Kim and Miguel Angel. I also want to thank Michel and Alejandro for their enormous support in the execution of the haptic experiments.

Lastly, I would like to thank Stacy M. Lane and Stephanie J. Schmidt for their support and advice.

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GLOSSARY

Cognitive Learning: “Demonstrated by knowledge recall and the intellectual skills: comprehending information, organizing ideas, analyzing and synthesizing data, applying knowledge, choosing among alternatives in problem-solving, and evaluating ideas or actions” (Lane, C. (n.d)).

Electromagnetism: “The physics of the electromagnetic field: a field which exerts a force on particles that possess the property of electric charge, and is in turn affected by the presence and motion of those particles” (Brewster, 2010, p. 10).

Haptic: “The study of touch and the human interaction with the external environment through touch” (Minogue & Jones, 2006, p. 318).

Pedagogy: “A general designation for the art of teaching” (Hall, 1905, p. 375).

Visuohaptic: The brand of virtual reality that focuses on simulation and stimulating the human through the sense of touch (Bayart, Drif, Kheddar & Didier, 2007).

ABSTRACT

Sanchez Martinez, Karla L. M.S., Purdue University, December 2013. The impact of visuohaptic simulations for conceptual understanding in electricity and magnetism. Major Professor: Alejandra J. Magana.

The present study examined the efficacy of a haptic simulation used as a pedagogical tool to teach freshmen engineering students about electromagnetism. A quasi-experimental design-based research was executed in two iterations to compare the possible benefits the haptic device provided to the cognitive learning of students. In the first iteration of the experiment performance of learners who used visual-only simulations was compared to the performance of those who used visuohaptic. In the second iteration of the experiment modifications were made to learning materials and experiment procedures to enhance research design. Research hypothesis states that multimodal presentation of information may lead to better conceptual understanding of electromagnetism compared to visual presentation alone.

CHAPTER 1. INTRODUCTION

1.1 Introduction

With the advancement of interactive technologies, new forms of complex simulations are becoming available. As a result, innovations are challenging educational researchers to identify how these technologies can be used to effectively support learning in new and unimagined ways. One of these devices is the force-feedback haptic technology, which provides computer controlled force variations to learners.

The application and study of haptic technology has had a tremendous growth since technological and computational researchers are able to contribute with the development, testing and deployment of computer simulations and haptic tools (Minogue & Jones, 2006). With the aim of continuing this research, the present study demonstrates an exploratory case of the potential impact haptic force feedback could provide to the students' cognitive learning. This research study has been conceived as a design-based research with a quasi-experimental approach. Exploring the impact of haptic technologies on students' learning processes and engagement in naturalistic learning contexts is the main objective of the study.

1.2 Background

Research in physics education has suggested that students often have ideas of how systems act or work in the physical world. However, in cases where the phenomenon is non-tangible, invisible to the naked eye, abstract, or counterintuitive, these concepts can generally result on misconceptions or alternative ideas that contradict scientific facts (Maloney, O'Kuma, Hieggelke, & Van Heuvelen, 2001).

Research has suggested that even after long periods of instruction, students do not demonstrate a significant improvement in their learning performance (Guisasola, Almudí, & Zubimendi, 2004). Furthermore, there is strong research evidence that abstract concepts, such as electromagnetism, are not fully understood among high school and college level students (Galili, 1995; Maloney et al., 2001; Raduta, 2005).

A main concern for educational researchers and educators has been finding ways to improve current learning techniques to consequently improve students' conceptual understanding. Using different educational strategies that could focus not only on the conceptual theory taught to learners, but also on the difficulties high school and university students encounter when learning abstract concepts has been recommended by various authors (Tornkvist, Pettersson, & Transtromer, 1993).

Current teaching methods are commonly known for their use of visual support, but despite current techniques, there is still a less explored teaching area that uses force feedback technology as an aid to visual educational materials. Modern learning theories, such as the theory of embodied cognition, suggest that learners use their perceptual and psychomotor systems to learn, besides their conceptual system (Adams, 2010). Based on this theory, the use of haptic technology, which requires the learners to use their perceptual and psychomotor skills, could highly impact current teaching methods and techniques, and hence improve learning.

1.3 Significance

Haptic technology has just recently been highly used in computer simulations for educational and training purposes (e.g., Jones, Minogue, Tretter, Negishi, & Taylor, 2006; Morris, Tan, Barbagli, Chang, & Salisbury, 2007). Various authors suggests that the performance of psychomotor skills is better with visuohaptic feedback rather than with information transmitted either through visual or physical channels (Morris et al., 2007). For this reason, haptic technology has been increasingly used in flights and medical teaching applications (Minogue, Jones, Broadwell, & Opewall, 2006).

Nevertheless, “the sense of touch has emerged as an understudied and perhaps under-utilized teaching tool” (Minogue & Jones, 2009, p.1363). Although according to Minogue and Jones (2009) there is enough evidence that proves that the sense of touch provides cognitive benefits to memory and learning, there is only a “handful of studies that directly or systematically explored this line of inquiry” (p. 1364).

Few recent studies that have reported the use of haptic applications for conceptual understanding of abstract science concepts, such as viruses and cells, have provided positive results on students’ engagement and interest in the activity in place (Jones et al., 2006; Minogue et al., 2006). However, electromagnetism has been a topic that has had less attention in regards to the implementation of haptic technologies.

Additionally, several studies analyzed as a review of literature regarding haptic technology in educational environments have demonstrated that there has been no research on the students’ cognitive learning of electromagnetism using haptic technology. Table 1.1 shows a summary of the stated literature review (Minogue & Jones, 2006). The information available in the table provides evidence to assume that the lack of research in the cognitive learning area of electromagnetism and haptic technology is latent.

Table 1.1. Descriptive summary of the selected developmental studies (Minogue & Jones, 2006).

Study	Participant ages	N	Stimuli
Stack & Tonis (1999)	Infants (7 months)	48	Real objects with varying textures (e.g., corduroy, silk, dish sponge)

Table1.1. Continuing.

Klatzky, Lederman & Mankinen (2005)	Infants (3 years and 11 months to 4 years and 11 months)	10	Real objects varying on five attributes (weight, size, roughness, hardness, and shape)
Berger & Hatwell (1995)	Children (5 years, 9 years); adults (21 years)	48	Cubes (16) varying in hardness and texture density dish sponge)
Alexander, Johnson, & Schreiber (2002)	Children (4 to 9 years)	36	3-D models of dinosaurs and sea creatures
Lederman & Klatzky (1987)	Adult (mean of 26 years)	18	Real 3-D objects (36 sets) varying along one of nine attributes (general and exact shape, volume, weight, texture, hardness, temperature, part motion and function)

Furthermore, from the not-extensive but thorough research provided by Minogue and Jones (2006), a lack of haptic exploration with participants at a high school and university level was also identified. Additionally, several researchers have stated that although there has been progress in investigating how students learn electromagnetism, this progress is relatively small compared to the research developed in areas like mechanics (Fredette & Lochhead, 1980).

1.4 Statement of Purpose

The present study examines the impact of haptic technology coupled with visual simulations (visuohaptic technology) in students' cognitive learning of abstract concepts. Understanding and assessing students' cognitive learning through the exposure of parallel multimodal visual and haptic sensory levels is the main aim of this research.

Using the positive results obtained from haptic technology when used as a cognitive tool for conceptual understanding of science abstract concepts as a foundation (Jones et al., 2004; Minogue et al., 2006), and the necessity for novel educational strategies (Tornkvist et al., 1993), this study evaluates the impact of the use of visuohaptic simulations as a pedagogical tool on a group of freshmen college students to convey electromagnetism related concepts.

Understanding the impact of these new technologies on students' learning can help educators and instructional designers to inform the design of future technologies and teaching practices.

1.5 Research Questions

The research questions for this study are:

1. Can students improve their conceptual understanding of electromagnetism concepts after being exposed to visual and visuohaptic simulations?
2. Are visuohaptic simulations more effective as a pedagogical approach than visual simulations alone for learning electromagnetism concepts; specifically, Coulomb's Law, and Electric and Magnetic field?

1.6 Assumptions

The present study is based on the following assumptions:

1. There is a need for new teaching methods that encourage students' understanding of abstract concepts, such as electromagnetism.
2. Electromagnetism is an abstract concept that has been proven to be difficult to understand by students.
3. Students have a similar level of understanding of electromagnetism concepts.
4. It is assumed that students have a high school level knowledge of electricity and magnetism concepts.

1.7 Limitations

The current study presents several limitations.

1. It will be assumed that during the take home pretest students will not consult any external materials or resources as instructed.
2. Each group in the experiment will have a maximum of 16 students.
3. Students will complete the experiment during their assigned laboratory session.
4. The experiment will be performed throughout a week.
5. The amount of extra points assigned to students who complete the experiment will be decided by the main instructor of the course.

1.8 Delimitations

The delimitations presented in this research study are the following:

1. The sample selection will consist of students enrolled in the course entitled ECET 120-Gateway to EET offered at the Electrical Engineering Technology department at Purdue University.
2. The study will be performed using two simulations, one for the concept of electric charges and one for the concept of magnetism.
3. The haptic device used throughout the experiment will be the Falcon Novint Haptic Device.
4. The experiment and the collection of the data will occur during the second week of October, 2013.
5. Students will complete the experiment voluntarily.
6. Participants who fail to complete all the assessments will be disregarded from the overall sample.
7. Used as a motivation to participate in the experiment, participants will receive extra credit for completing all the assessments.
8. Pretest and posttest tasks are a compilation of 12 questions from the Survey of Conceptual Knowledge of Electricity and Magnetism (Maloney et al., 2001).
9. The pretest and posttest tasks will focus on four main topics: Coulombs' law, magnetic force, electric force and field superposition and magnetic field caused by a current.

10. Students will be assigned to one of two conditions, control or experimental, based on the random assignment of the entire laboratory session.
11. In the research implementation, students will be allowed to complete the pretest assessment individually as a take-home task.
12. The extra credits provided to students for completing the tasks will not influence the final score obtained in the course.

1.9 Chapter Summary

The present study aims to explore the potential impact of visuohaptic simulations on the cognitive learning performance of students when learning electromagnetism related concepts. The experiment sample consisted of freshmen students from an Electrical Engineering Technology course. Participants were assigned to one of two treatment conditions, a control group that used visual simulations without the force feedback, and an experimental group that used visual simulations plus force feedback. Any other experiment variable will be attempted to be kept identical for both treatments. Participants completed a pretest and a posttest assessment as part of the experiment. The pretest task was completed as a take-home task assignment, while the posttest task was completed during the students' laboratory session where the experiment took place. During the session, the students were allowed to explore the computer simulations using the Falcon Novint haptic device as an aid. Participants from the control condition used the haptic device; however, the force feedback functionality was disabled.

The experiment and its data collection occurred throughout the duration of a week. The laboratory sessions consisted of a maximum of 16 students, and lasted a maximum of three hours. The pretest and posttest assessments were analyzed based on four main electromagnetism related concepts: Coulombs' Law, Magnetic Force, Electric Force and Field Superposition, and Magnetic Field Caused by a Current. Students' results will provide a foundation to understand the potential added value that occurs when electromagnetism concepts are learned by university students by coupling haptic technology with visual simulations.

CHAPTER 2. LITERATURE REVIEW

2.1 Literature Review

The literature review of the present research study addresses prior work related to the difficulty students engage when understanding abstract physics concepts, specifically targeted to electromagnetism concept learning. Additionally, research studies immersed in the cognitive and learning approach of haptic technology are described. Further examination on the use of haptic devices as pedagogical tools in the teaching area of electromagnetism will be explained in the following section.

2.1.1 Students Misconceptions in Electricity and Magnetism

Authors Chabay and Sherwood (2006) creators of the Brief Electricity and Magnetism Assessment (BEMA) stated that it is important for students to have a clear understanding of electromagnetic concepts and interactions since they represent the foundation of many current and novel technologies. However, teaching abstractions in a clear and understandable format is not an easy task for instructors. Authors mention that

> science and engineering students are introduced to E&M in the second half of the introductory calculus-based physics course, after […] an

> introduction to classical mechanics. However, even students who have done well in the first part of the course often find E&M to be difficult and confusing. (Chabay & Sherwood, 2006, p.329).

Similar to the previous findings, various authors have argued that students often have difficulties and experience misconceptions on E&M concepts, such as in “electromagnetic induction and electric potential and electric energy” (Dega, Kriek, & Mogese, 2013, p.679). Several reasons on why students experience difficulties when learning E&M are related to the abstract, complex and invisible nature of the concepts. Authors explain that “in E&M the student is quickly introduced to a world in which almost all the quantities are invisible; they are either microscopic such as electrons or abstractions such as field, flux, and potential.” (Chabay & Sherwood, 2006, p.329). Authors Bagno and Eylon (1997) stated that electromagnetism courses “usually involve a mathematical treatment of central relationships and sophisticated problem-solving tasks” (p.726). For authors Chabay and Sherwood (2005), students have not experienced and hence are not prepared for the complexity that the new mathematical problems present.

In addition to the previous mentioned statements, students often encounter difficulties when trying to apply physics laws to electromagnetism situations. Author Galili (1995) explained that a reason of the difficulties appear when there is no inter-relation of the concepts, for example in the case of the field concept.

Students do not clearly observe a relation of this concept through mechanical and electromagnetism courses. In a similar perspective, several authors have described that physics students often cannot distinguish between the concepts of fields and field lines (Tornkvist et al., 1993). A possible reason to this learning problem can be explained by the relationship between the difficulty of the concepts and the traditional teaching approach:

> Students can easily be overwhelmed by this rapid introduction of abstract ideas and usually are not given sufficient practice to be able to apply these concepts reliably, or to discriminate them from each other. The rapid introduction of new concepts and escalation in complexity frequently confirms in students' minds the conviction that physics consists of a large number of disconnected formulas. (Chabay & Sherwood, 2006, p.329)

Besides the previous research evidence, exploration on students' understanding of physics concepts has provided results that are below educators' expectations. Authors Maloney et al. (2001) obtained weak and disappointing results on both pretest and posttest assessments when testing more than 5000 students utilizing the authors' Conceptual Survey in Electricity and Magnetism. Bagno and Eylon (1997) applied a written questionnaire to 250 students age 17- 18 related to electricity and magnetism where "results suggest that students' knowledge representation is deficient in several respects" (p.734). Research made in the same areas of E&M has found similar results (e.g., Albe, Venturini, & Lascours, 2001; Greca & Moreira, 1997).

Current teaching E&M methods are not addressing the problem students encounter when initially exposed to the concepts. Dega et al. (2013) stated that “students face most of the concepts in E&M in school learning in the context where teachers mostly use the traditional transmission model” (p.680). Chabay and Sherwood (2006) explained that a common teaching approach for E&M concepts is to “gloss over it, going through the fundamentals at high speed, and spending most of the course on rote problem solving” (p.329).

Based on this problematic, Törnkvist et al. (1993) recommended using different educational strategies that could focus not only on the conceptual theory but also in the cognitive obstacles that physics university students’ may encounter when learning abstract material. Galili (1995) explained that in order “to prevent some specific mistakes students make while considering the field context, physics instruction should not be limited only to the formal operational definition of field strength but should include an explicit and more didactically elucidated elaboration of the field concept” (p.385). The necessity for novel educational strategies that could increase the performance and understanding of abstract Electricity and Magnetism concepts for physics students serve as a motivation to develop new teaching models and techniques.

2.1.2 Simulations in Physics Education

Education in science fields such as Physics, and more specifically in topics like Electricity and Magnetism, has found learning support on physical, hands-on activities (Jones, Andre, Superfine, & Taylor, 2003; Minogue & Jones, 2006). Learning by doing allows students to “interact directly with the material world using the tools, data collection techniques, models and theories of science” (de Jong, Linn, & Zacharia, 2013, p.305). However, novel devices, computer software, as well as simulated environments can provide an alternative for physical scenarios. Various authors state that “3D environments have the potential to situate the learner within a meaningful context to a much greater extent than traditional interactive multimedia environments. […] They can allow the learner to explore places that cannot be physically visited” (Dalgarno, Bishop, & Bedgood Jr., 2003, p.91). Aligned with the previous statement, Kocijancic and O’Sullivan (2004) stated that computers can “simulate or animate specific scientific phenomena, […] simulate complicated, expensive and/or inaccessible devices […] or replace environmentally hazardous laboratory experiments” (p.239).

The substitution of hands-on activities and equipment for computer simulations was proven by authors Triona and Klahr (2003) to have the same or even better results based on the same educational scenario and curriculum (as cited in Finkelstein et al., 2005). A similar research study found that “properly designed simulations used in the right contexts can be more effective educational tools than real laboratory equipment” (Finkelstein et al., 2005, p.1).

According to Rutten, van Joolingen, and van der Veen, (2012) simulations can provide the needed visualization of the different abstractions and complexities found in E&M concepts (as cited in Dega et al., 2013). Simulations “motivate and actively engage students towards construction and reconstruction of conceptual knowledge in their learning of abstract concepts in the microscopic physical world” (Jimoyiannis & Komis, 2001, as cited in Dega et al., 2013, p.679). Used E&M simulations help “situate interactive engagements and to explicit visual representations in students’ learning of E&M concepts” (Dega et al., 2013, p. 680). Authors sustained their decision of using computer simulations based on several literature articles (Akpan & Strayer, 2010; Bayraktar, 2002; Bell & Trundle, 2008; Finkelstein et al., 2005; Huppert, Lomask, & Lazarowitz, 2002; Jaakkola, Nurmi, & Veermans, 2011; Pyatt & Sims, 2012;Winn et al., 2006; Zacharia, 2007). This abundant evidence demonstrates how computers and virtual laboratories provide “equal if not greater learning gains” over physical scenarios (Dega et al., 2013, p.680).

2.1.3 Haptic Technology

As technology evolves, new forms of complex virtual reality simulations are becoming available to users. However, these complex simulations or devices are not only targeted for users to be ‘seen’, but also to be ‘felt’ or ‘touched’. Until a few decades ago, the interaction of users with computers or with visual simulations relied mostly on the users’ sense of sight. Authors Thurfjell, McLaughlin, Mattson, and Lammertse (2002) described this interaction as “although touch is one of the most fundamental ways people interact with physical objects, the interaction with virtual objects in the computer world has until recently been restricted to the use of vision as the primary mode of receiving information” (p.210). The technology field that focuses on the interactions of users and virtual worlds through the users’ sense of touch is called haptic. The term “haptics” was first introduced in 1931 by author Revesz (1950). The word comes from the Greek words *haptikos,* meaning “able to touch,” and *haptesthai,* meaning “able to lay hold of” (Revesz, 1950; Katz, 1989, as cited in Minogue & Jones, 2006, p. 318).

The first haptic telephone patent was given to Thomas D. Shannon in Dec. 18, 1973 (Shannon, 1973). The device consisted of a grip attachment that would send force feedback through pressure and volume variations between two or more parties. The first widely available haptic device was the SenSable Technologies PHANTOM developed in 1993 (Thurfjell et al., 2002). The PHANTOM “is a small, desk-mounted robot-like arm that permits simulation of fingertip contact with virtual objects through a pen-like stylus” (Jones et al., 2006, p. 113).

Haptic technology has nowadays evolved, and is providing users with a wide range of devices that perform different but unique functionalities. This uniqueness allows haptic technology to be divided into different categories. A proposed classification of haptic devices was to organize them between admittance control or impedance control equipment (Thurfjell et al., 2002). Admittance control criterion occurs when users supply force to move the object(s) in the simulation and the object(s) move, “force in, displacement out” (Thurfjell et al., 2002, p. 212). Impedance control, on the other hand, is the opposite idea, the user moves the object(s) in the simulation, and the device provides force feedback, “displacement in, force out” (Thurfjell et al., 2002, p.211).

A second type of classification divides haptic devices into tactile and kinesthetic instruments. Tactile haptic devices focus on providing sensations, such as thermal feedback, edges, vibrations or surface properties to the cutaneous level of the user’s body. Kinesthetic devices provide forces, vibrations or weights to the user (Harris, n.d.). A clear example that demonstrates the difference between tactile and kinesthetic concepts can be illustrated by a user holding a tennis ball. While the user’s finger pads can feel the temperature and outer surface of the ball (tactile), the user’s hand and other arm muscles can feel its weight (kinesthetic).

Haptic technology is rapidly evolving, allowing the integration of new and novel techniques. These modern strategies are constantly providing users with new forms of interaction and realistic virtual experiences. For instance, researchers are introducing new senses to the haptic modality, such as the sense of smell (Spencer, 2005). Furthermore, these novel devices are now integrating a new affordance level of interaction by providing torque (Jones & Magana, in press).

2.1.4 Haptic Technology for Electricity and Magnetism

Research has proven that for students it is more effective to learn abstract concepts when there is “touch” or manipulation of objects than when there is only visual support (Druyan, 1997; Glasson, 1989; Jones & Vesilind, 1996). Educators believe that hands-on activities are influential learning tools that can improve student learning and performance (Minogue & Jones, 2006). Haptic devices can be used as learning tools to support hands-on experiences. For instance, they can simulate object hardness, weight, and inertia, and through the use of computer software, enable users to feel’ and explore the characteristics of virtual objects and worlds (McLaughlin, Hespanha, & Sukhatme, 2002). Haptic devices additionally allow the users, or in an education context the learners, to explore three dimensional abstract scenarios or objects (Jones & Magana, in press). This possibility enables students to access invisible-to-the-eye scenarios (electric fields) or unreachable science situations (universe or atoms) where, supported by the feedback provided by the device, users can create or improved their representational mental models (Jones & Magana, in press). Authors also state that there is a “significant potential for haptic technology to be a useful learning tool for young children” (p.1).

According to theories of embodied cognition (Monuteaux, Faraone, Herzig, Navsaria, & Biederman, 2005; Sexton, Gelhorn, Bell, & Classi, 2012) physical laboratories take advantage of tactile information to improve conceptual change. Several researches on embodied cognition argue that cognition not only takes place in the learner's conceptual system, but in the "perceptual and motor system as well" (Adams, 2010, p. 619). Based on this theory and the evidence that haptic devices can simulate tactile information for virtual and remote laboratories, virtual hands-on laboratories can be designed to improve the acquisition of learning through tactile haptic technology.

Through the implementation of computer technologies and haptic devices, instructors can create virtual hands-on laboratories that simulate real life scenarios or even physical abstractions. In these laboratories students are able to explore phenomena by manipulating technology, collecting data and exploring virtual simulations (Dalgarno et al., 2003; Kocijancic & O'Sullivan, 2004). In virtual laboratories the students' experiences can be adapted to fulfill a certain goal. The simulations can be modified to eliminate confounding concepts and augment the main conceptual material. Nevertheless, there is still further research to be made in order to recognize the true value of virtual laboratories, and its possible substitution of physical hands-on laboratories. (de Jong et al., 2013)

Most of the exploration on conceptual learning has focused on teaching abstract concepts such as viruses and cells (Jones et al., 2006; Minogue et al., 2006). However, due to research mixed or contradictory results, "there is less of a consensus as to how to assess accurately the efficacy of these technologies" (Minogue & Jones, 2009, p.1359). Further research is needed in order to obtain conclusions on whether the use of the device helps users improve their learning (Feygin et al., 2002; Morris et al., 2007; Srimathveeravalli & Thenkurussi, 2005; Yokokohji et al., 1996).

2.2 Theoretical Framework

The present research study is based on two educational theories: Conceptual Change (Chi, Slotta, & De Leeuw, 1994; Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1982) and Dual Coding Theory (Paivio, 1991). Each theory is described and its approach is related to the present study in the following sections.

2.2.1 Conceptual Change

Conceptual Change is the learning theory that serves as the foundation to lead the conceptual procedures used in the present study. This theory can be briefly defined as the "learning that changes some existing conception" (Chi et al., 1994, p.28). Conceptual Change assumes that learners possess prior knowledge or mental models. Authors Strike and Posner (1982) explained conceptual change as the "transformation of current knowledge" (p. 232). They state that individuals possess a set of ideas, often presented as misconception, which later affect the information that is learned and the form in which that information is acquired (Strike & Posner, 1982). These misconceptions are "viewed as students' attempts to interpret scientific information within an existing framework theory that contains information contradictory to the scientific view" (Vosniadou, 1994, p.46). A highly important goal for science instructors that could improve and enhance the learning experience of students is to “study the mechanism underlying conceptual change” (Carey, 2000, p.17).

Author Vosniadou (1994) identified two procedures in which mental concepts can change: either through enrichment or revision. Enrichment provides new information to the existing mental models of the learners, while revision involves the modification of current conceptual information according to changes in the theory. Enrichment is considered the easiest form of conceptual change. However, revision, can be hard to obtain if the beliefs of the learner are tied to a framework theory. In that specific case, the author explained that the modification of a framework theory is difficult “because the presuppositions of the framework theory represent relatively coherent systems of explanation based on everyday experience and tied to years of confirmation” (p.49).

A different approach of Conceptual Change can be observed in the distinct models that depict from this theory. Authors Hewson and Hewson (1984) explain conceptual conflict as one strategy of the Conceptual Change theory. This strategy states that students often have “theories about how the natural world works which they bring to their science classes” (Resnick, 1983, as cited in Hewson & Hewson, 1984, p.2). Authors explained that these theories often differentiate from scientific facts, and hence create a conceptual conflict for students (Hewson & Hewson, 1984). Along the same lines, authors Posner et al.,

(1982) suggested “that learning occurs when the learner recognizes a need and becomes dissatisfied with their existing conceptions” (as cited in Dega et al., 2013, p. 680). This dissatisfaction creates a conceptual conflict in students, often triggering additional inquiry and exploration actions to acquire a better understanding of the concepts. However, in order for students to realize of this dissatisfaction the new, alternative concepts need to be intelligible, plausible and fruitful (Hewson & Thorley, 1989; Strike & Posner, 1982).

A second strategy that unfolds from the Conceptual Change theory is the cognitive perturbation approach. The cognitive perturbation approach “provides appropriate perturbations to initiate students’ conceptual change towards viable intermediate conceptions, which are more scientific than their preconceptions, before suddenly reaching scientific conceptions” (Li et al., 2006, as cited in Dega et al., 2013, p.682). This strategy states that it is necessary to know the environment where the student is learning in order to address the correct type of perturbation needed to create conceptual change (Dega et al., 2013). By determining students’ preconceptions, instructors can create a more defined method that improves students’ knowledge, taking into consideration their intermediate conceptions. Authors Dega et al. (2013) described the cognitive perturbation strategy as an evolutionary learning method due to its focus on improving and merging knowledge considering students’ intermediate conceptions.

Based on the approach of the Conceptual Change theory, the present research study aims to provide students with the needed conceptual information in a manner that promotes conceptual change of their current mental models and helps them acquire scientific facts with ease. Additionally, the learning materials presented follow to their greatest extent the necessary conditions to create conceptual change: intelligible, plausible and fruitful information (Hewson & Thorley, 1989; Strike & Posner, 1982).

2.2.2 Dual Coding Theory

Paivio's Dual Coding theory guided the design of the pretest-posttest quasi-experimental design (1971, 1986, 1991). Dual Coding theory suggests that learners demonstrate a better conceptual understanding when information is simultaneously presented in different communication channels (Paivio, 1986, as cited in Minogue & Jones, 2006). According to this approach, communication channels are conformed of visual and auditory sensory levels, each having their own working memory. Authors Jones et al. (2006) state through Paivio's theory (1986) that "kinesthetic and tactile experiences may be encoded not as verbal information but instead as a type of image". According to working memory theories, "if each modality has its own working memory, it is thought that if multiple channels or modalities are employed the cognitive load on a student can be reduced" (Mousavi, Low & Sweller, 1995, as cited in Jones et al., 2006). Jones and Magana (in press) hypothesized that "the use of different channels for processing is believed to lead to different types of conceptualizations and representations than would be created by only one channel.” (p.1)

Clark and Paivio (1991) explained that mental schemas are conformed by different verbal and non verbal features and “retain properties of the concrete sensorimotor events on which they are based” (p. 151). Verbal modes represent information that can be communicated in verbal codes using vision, audio or articulatory codes. Non verbal modes consist of sounds, images, emotions or events (Clark & Paivio, 1991).

Other researchers have argued that tactile feedback has the same potential role in learning as the visual and auditory channels that were first described in Dual Coding theory (Jones, 2006). Based on the dual coding theory, and the properties of sensorimotor events, the present study will examine these premises to determine if the use of different (independent or parallel) channels supports better achievement of conceptual understanding.

CHAPTER 3. METHODOLOGY

3.1 Design-based Research

The methodology used for this study was based on design-based research. Authors Barab and Squire (2009) described design-based research “not so much as an approach as it is a series of approaches” (p.2). Sandoval and Bell (2004) referred to design-based research as the “theoretically framed, empirical research of learning and teaching based on particular designs for instruction” (p. 200). Furthermore, The Design-Based Research Collective (2003) described design-based research as “an important methodology for understanding how, when, and why educational innovations work in practice” (p.5).

Design-based researches are characterized for four main features according to Barab and Squire (2009): they are known for producing models and practices on learning and teaching, for being interventionist, iterative (Cobb, 2001; Collins, 1992), and for being reproduced in naturalistic environments. A fifth characteristic stated by The Design-Based Research Collective (2003) is that design-based research needs to consider how the naturalistic environment impacts the form design functions, “the development of such [considerations] relies on methods that can document and connect processes of enactment to outcomes of interest” (p.5). The main goal of design-based research focuses on creating, through the study of how learning occurs, models, theories and instructional strategies on learning activities or practices which can better improve learning in naturalistic environments (Barab and Squire, 2009; Brown, 1992; Collins, 1992; Sandoval & Bell, 2010; The Design-Based Research Collective, 2003).

The present study utilizes design-based research and its series of approaches on two iterations: one was a quasi experimental research design and the other one was an expert evaluation. Figure 3.1 represents how research and design intertwined to form the stages executed throughout this study.

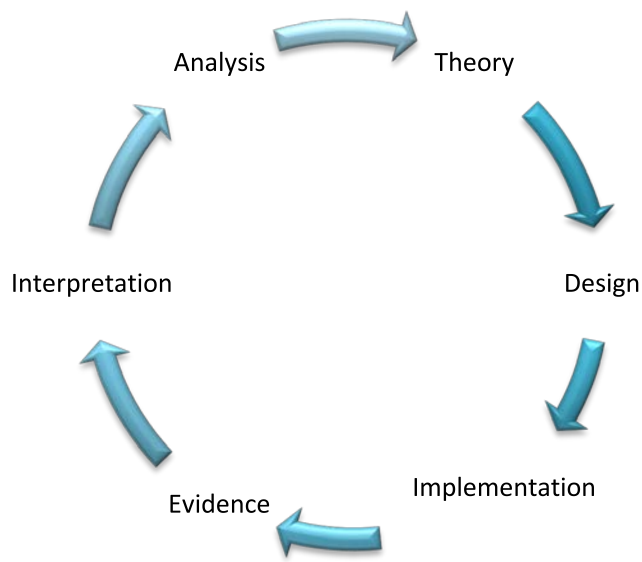

Figure 3.1. Design-based research stages.

Initially, the research design was developed to observe and investigate the possible benefits that students' learning could acquire when learners are not only exposed to visual material but also to tactile feedback from a haptic device. During the design development stage treatment groups and their characteristics were established:

- Experimental group: Participants were exposed to visual simulations and received force feedback from the haptic device.
- Control group: Participants were exposed to visual simulations but did not receive force feedback from the haptic device.

The research design included the implementation of a pretest and a posttest assessment. Figure 3.2 shows the series of activities that students were directed to perform according to the design stated in the first iteration of the study. Initial activities included completing the pretest assessment, exposure to a PowerPoint lecture, exploration of two visual or visuohaptic simulations, and completing a posttest assessment.

Figure 3.2. Activities performed during the first iteration of the research.

After the design phase, the implementation stage was executed. The following chapter, Chapter 4, explains and details the different parts and elements that constituted the implementation of the first iteration of this design-based research process.

CHAPTER 4. STUDY 1: CLASSROOM IMPLEMENTATION

4.1 Methodology: Classroom Implementation

The first iteration in this research process consisted on the implementation of a quasi-experimental design that served to investigate the impact of visual simulations coupled with haptic technology on electromagnetism concepts learning.

4.1.1 Learning Materials

Learning materials consisted of two computer simulations and a haptic device. The subject domain of the first simulation was magnetism. The simulation consisted of two bar magnets with color arrows representing magnetic field vectors enclosing a bar magnets (see Figure 4.1). The colors indicated the intensity of the magnetic fields (e.g., red- strong, blue- weak). The trajectory of the force was represented by the direction of the arrows.

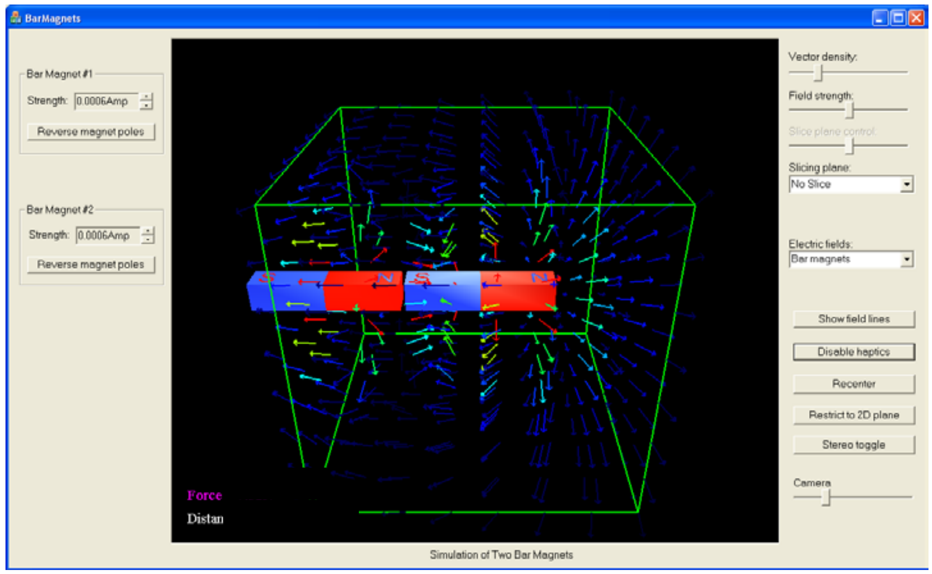

Figure 4.1. Bar Magnets simulation.

Participants were allowed to modify different characteristics of the bar magnets, such as the strength of their respective poles. Additionally, learners were able to reverse magnetic poles, hide or accentuate vector arrows, and increase or decrease the strength of the magnetic fields. Lastly, the simulation enabled participants to observe different angles of the magnetic field vectors through 3-D rotation. However, this rotation was limited to a forward and backward motion.

In addition to the simulation, participants in the experimental condition experienced a force feedback (e.g. attraction or repulsion) provided by the haptic equipment, when approximating the bar magnets' poles.

The subject domain of the second simulation consisted of concepts related to electrically charged particles, more specifically, Coulomb's Law. The simulation started with initial explanations about Coulomb's Law and the behavior of charged particles. The simulation then displayed a screen with two static particles (Figure 4.2), as well as a second positive particle controlled by the user and the haptic device. For the static particles their electric fields were displayed as static field lines indicating the direction of the field vectors. Participants were able to use the haptic device to maneuver the positively charged particle around the simulation's screen, except when overlapping with the static particles.

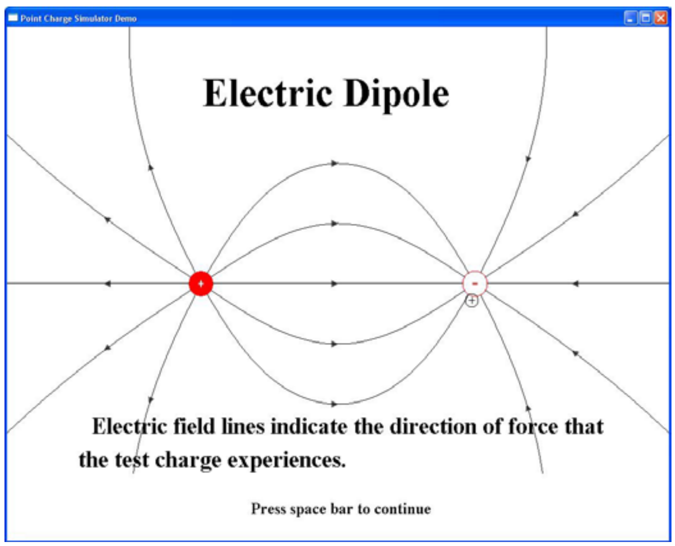

Figure 4.2. Charged particles simulation.

Participants in the experimental group were able to feel an attractive force or vibration when approaching the positive particle closer to the negative static particle. Similarly, participants felt a repulsion force when moving the positive particle closer to the positive static particle. Participants in the control group were able to move the positive particle around the screen but no force vibrations were induced by the haptic device at any time.

Both simulations were manipulated using a haptic device called Falcon Novint (Figure 4.3). The Falcon Novint is a 3-D haptic joystick commonly used in video gaming. Participants operated the haptic device by holding the device's grip and moving it in different positions at will.

Figure 4.3. Falcon Novint haptic device.

4.1.2 Participants

Participants in this study included freshmen students from an Introductory Electrical Engineering Technology course at Purdue University. The present introductory class consisted of approximately 75 students (95% male students and 5% female students). Since freshmen students are considered to have recently graduated from high school, their most important characteristic was that their electricity and magnetism knowledge is assumed to be similar to that of high school students. According to high school students' curricula (9 – 12 grades) from the On-line benchmarks of Project2061.org (n.d.) by AAAS, the main topic

"Forces of Nature" includes concepts such as electromagnetism, motion, magnetic forces, etc. According to these standards, at the end of 12th grade students should be able to have a "sense of electric and magnetic force fields (as well as of gravity) and of some simple relations between magnets and electric currents [...] The priority should be on what conditions produce a magnetic field and what conditions induce an electric current" (Project2061.org).

4.1.3 Procedures

Once the design was planned and structured, data collection took place during a one-week period toward the middle of the Fall 2012 semester. Pretest and posttest assessments were explicitly stated as voluntary; however, students received extra credit in their Electrical Engineering Technology course for the accomplishment of the complete set of tasks involved in the research study. Data was collected through an online survey application called Qualtrics. The amount of extra credit students received in their course was assigned by the course's main instructor, and had no relation with the participants' performance in the experiment or assessments. Participants had only one opportunity to complete each of the assessments (e.g. pretest and posttest), and questions were validated to not being left unanswered.

4.1.4 Data Collection

Selected questions from Maloney et al. (2001) "Conceptual Survey in Electricity and Magnetism" (CSEM) were used as the data collection method. The complete conceptual survey covers eleven topics, from which four were selected for the present study: Coulomb's force law, Electric force and Field superposition, Magnetic force and Magnetic field caused by a current. The pretest and posttest instruments were identical, and included three questions from each of the selected topics, consisting of a total of twelve items, see Appendix A.

Aside from these twelve electromagnetism questions, the survey instrument also included three open ended questions that asked participants their name, their assigned laboratory session, and whether they are taking or have previously taken any Physics courses.

4.1.5 Data Analysis

The data analysis started by interpreting responses similar to authors Maloney et al. (2001), and by identifying students' understandings of electricity and magnetism. Then, data was analyzed using descriptive and inferential statistics. During the descriptive analysis, average scores and standard deviations were calculated for pretest and posttest scores.

Participant's responses were coded as (0) incorrect (1) correct, and analyses were performed for: learning condition, complete sample pretest-posttest scores and by questions' topics. The coded data was later analyzed using inferential statistics. Initial evaluations of the pretest results were examined by learning condition and by questions' topics. A paired t-test model was used to compare the performance of each learning condition and to assess whether there were any significant differences among groups or items' topics.

4.1.6 Validity and Reliability of the Instrument

The Conceptual Survey in Electricity and Magnetism was previously verified and assessed by Maloney et al. (2001). Maloney and colleagues validated the survey by asking 42 professors to rate each of the items on a 1-5 scale (1 being low and 5 being high) on reasonableness and appropriateness. Their results indicated that all of the items were rated as highly reasonable and appropriate. The KR 20 reliability score was .75 indicating good reliability.

An additional expert evaluation was also conducted as part of this study. Three researchers with expertise in electricity and magnetism and science education independently reviewed the instrument. Researchers' agreement on the appropriateness of the topics and questions targeted to freshmen students was used as a validation for the final instrument. In addition, a pilot study was conducted with seven senior physics students. The pilot study provided information about the duration of the study and also resulted in several minor revisions to the instruments. Students who participated in the pilot study provided the researchers with feedback about the level of difficulty of the procedures, the level of understanding of the explanations and potential revisions to the wording of the questions.

4.1.7 Ethical Conduct of Research

The present research study holds an approval to perform research with human subjects from the Institutional Review Board “IRB” from Purdue University. As stated in the exempt form, researchers kept extreme confidentiality of all the data collected throughout this experiment. Data was only collected in text format, and original documents were kept under a secured locked cabinet at Purdue University West Lafayette campus.

The information collected was not disclosed to the main instructor of the course until final grades were submitted. The electronic versions of the collected data were modified to include only participants’ identification codes. Names and other identifiable information were removed from all electronic documents.

4.2 Results Classroom Implementation

The present section reports the results and analyses of the pretest and posttest assessments for the control and experimental learning groups. Additionally, several analyses are reported on the performance of each treatment condition based on the questions’ topics.

4.2.1 Analysis of Responses by Concepts’ Topics and Learning Conditions

Participants’ responses were analyzed by question topic (Coulomb’s Law, Electric Force and Field Superposition, Magnetic Force and Magnetic Field Caused by a Current), and the scores were evaluated using t-tests. The objective of this analysis was to verify and examine trends in participants' responses according to the E&M topics, as well as significant differences between conditions. Responses were compared and describe following the evaluation performed by Maloney et al. (2001) in the Conceptual Survey in Electricity and Magnetism.

For each of the questions analyzed, responses were graphed and examined based on the pretest and posttest scores of the participant sample. Due to the coding procedure of 0 and 1, the highest score a participant could obtain in each of the topics' sections was 3 (three questions per topic). Responses were normalized to percentages on a 0-100 scale.

4.2.2 Coulomb's Force Law

Questions 1, 2 and 3 from the pretest and posttest assessments related to Coulomb's Force Law. Authors classified question 1 as "the easiest item overall" (Maloney et al., 2001, p. 16). Certainly, results show that the correct answer, choice B, obtained the highest percentage from the overall set of items with a 53% of correct answers in the pretest and a 66% in the posttest. An increase in correct responses from pretest to posttest was also noted. Results from question 2, however, showed a reduced number of correct responses. Authors relate this to "favored choice C indicate[s] that many students did not apply Newton's third law or symmetry of Coulomb's law to electric point charge situations" (p. 16). Again, similar to the performance of the experimental group from Maloney et al.'s study, our responses showed answer choice C as the second favored choice. Besides the fewer correct responses obtained in this question compared to the previous item, correct answer option B was conclusively the response with the highest percentage of correct answers.

Lastly, question 3 showed an increase in incorrect responses. Authors relate this issue as “confusion on both the effect of the magnitude of the charge and the distance of separation” (Maloney et al., 2001, p. 16). Answer choice D predominantly obtained the highest percentages of correct answers with a 50% in the pretest and 45% in the posttest. Contrary of the previous two analyses, question 3 resulted in fewer correct responses on the posttest than on the pretest test, Figure 4.4.

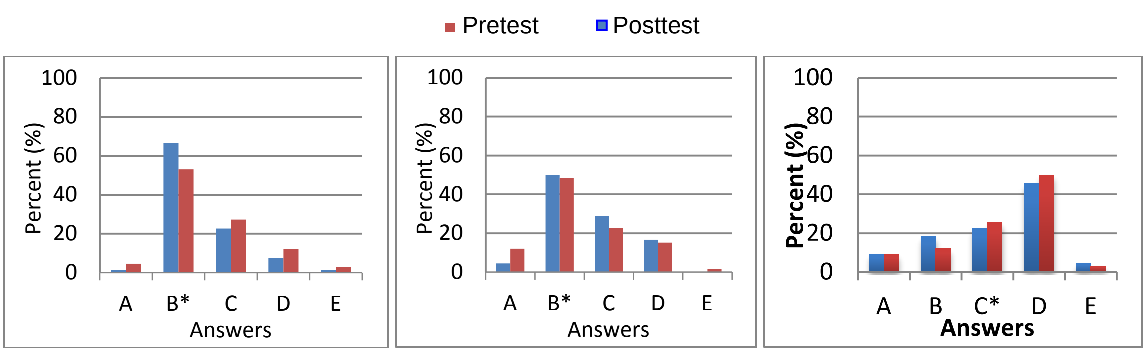

Figure 4.4. Graphical summary of participants’ responses for pretest and posttest assessments on Coulomb’s force law. Correct answers are marked with an asterisk.

For Coulomb’s law questions, the mean and standard deviation scores are shown in Table 4.1. Initial evaluations of the pretests results showed no significant differences between learning conditions. Analysis of the t-test evaluation showed no significant differences between control and experimental group mean gains, (t=.761, p>.05).

Table 4.1. Results of t-test analysis on pretest and posttest scores questions 1, 2 and 3.

	Condition	Mean	Std. Deviation	Normalized Mean
Pretest	Experimental	1.333	.8057	44.43%
	Control	1.185	.7357	39.50%
Posttest	Experimental	1.282	.7930	42.73%
	Control	1.556	.6980	51.87%

4.2.3 Electric Force and Field Superposition

Questions 4, 5 and 6 from the instrument related to Electric Force and Field Superposition. Question 4 reported a varied combination of choices from participants. Answer choices D and E obtained the highest percentages; however, analyses showed that correct answer E was the second favored choice with a low 28% of correct answers in the pretest and 30% in the posttest.

For question 5, the results show a high percentage of answers favoring option D in both pretest and posttest scores. Maloney and colleagues explain this relation as “A noticeable percentage of students seem to be confused about how a new charge affects the direction of the force or field” (Maloney et al., 2001, p. 16). The second preferred choice with the highest percentages was correct answer B, with 28% of responses correct in the pretest compared to 33% in the posttest.

Lastly, question 6 was the only question from the Electric Force and Field Superposition topic that received the highest percent of correct responses, choice B. A noticeable 42% of correct answers on the posttest surpassed the 24% reported on the pretest.

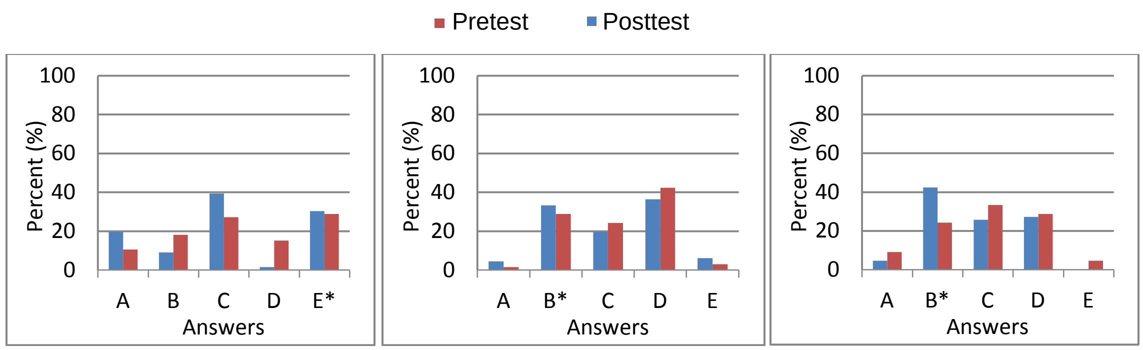

Figure 4.5. Graphical summary of answers for pretest and posttest assessments on Electric Force and Field Superposition. Correct answers are marked with an asterisk.

Electric Force and Field Superposition scores are shown in Table 4.2. Similar to Coulomb's Law, pretests results were analyzed for both conditions and significant differences were not found. Normalized results show a very similar performance for both learning conditions in the pretest assessment. On the other hand, posttest results show a difference between the two conditions, with the control group (e.g., no force feedback) presenting higher scores. However, t-test results showed no significant differences between conditions (t=-.244, p>.05).

Table 4.2. Results of t-test analysis on pretest and posttest scores questions 4, 5 and 6.

	Condition	Mean	Std. Deviation	Normalized Mean
Pretest	Experimental	.795	.9228	26.5%
	Control	.852	.9488	28.40%
Posttest	Experimental	.974	1.0879	32.47%
	Control	1.185	1.2101	39.50%

4.2.4 Magnetic Field Caused by a Current

Questions 7, 8 and 9 related to the topic Magnetic Fields Caused by a Current. In question 7, answers B and C were strong distracters for the students. Choice B indicated that students confused the effects of magnetic fields and the effects of electric fields. The percentage of students noting the correct answer A increased from pretest to posttest.

Question 8 tested how much students understood a “magnetic field created by a current carrying wire and superposition of these fields” (Maloney et al., 2001, p. 16). Although Maloney and colleagues classified this question as straightforward, our results show choices B and D were strong distracters for the students.

For question 9 the strongest distracter is choice E. Authors explained this relation by proposing that it “may be another electrical analog with two like charges and the point in between them having no net field”. Although almost half of the participants chose answer E, the correct answer C got the second highest percentage in the posttest results with a 24% of correct answers in the pretest and 22% in the posttest.

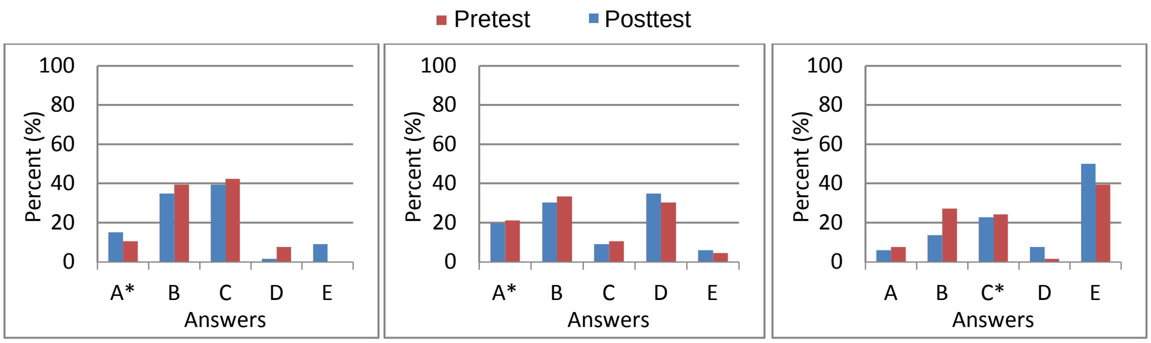

Figure 4.6. Graphical summary of answers for pretest and posttest assessments on Magnetic Field Caused by a Current. Correct answers are marked with an asterisk.

Similar to the previous two t-test evaluations, the data collected from the Magnetic Field Caused by a Current topic was analyzed and presented above. Table 4.3 reports the mean and standard deviation scores obtained from participants' responses to questions 7, 8 and 9.

Table 4.3. Results of t-test analysis on pretest and posttest scores questions 7, 8 and 9.

	Condition	Mean	Std. Deviation	Normalized Mean
Pretest	Experimental	.487	.8231	16.23%
	Control	.667	1.0000	22.23%
Posttest	Experimental	.590	.8801	19.67%
	Control	.556	.8006	18.53%

First, participants from the experimental condition showed lower achievement than the control group for the pretest assessment. However, pretests results showed no significant differences between groups. Posttests mean scores show that although the control group initially presented higher results, the experimental group obtained a higher total mean.

4.2.5 Magnetic Force

Questions 10, 11 and 12 assessed the topic of Magnetic Force. According to Maloney et al. (2001), in question 10 “students expect a magnetic force whenever an electric charge is placed in a magnetic field” (p. 18). Aside from the high variability presented in the responses obtained from question 10, posttest results show that preferred answer choice E received the highest percentage of responses.

However, for questions 11 and 12, pretest and posttest results show that in both cases the correct answer choice D was noted by only a few students. Maloney and colleagues (2001) suggest that this response indicates that students hold an incorrect concept confusing electric force with magnetic force.

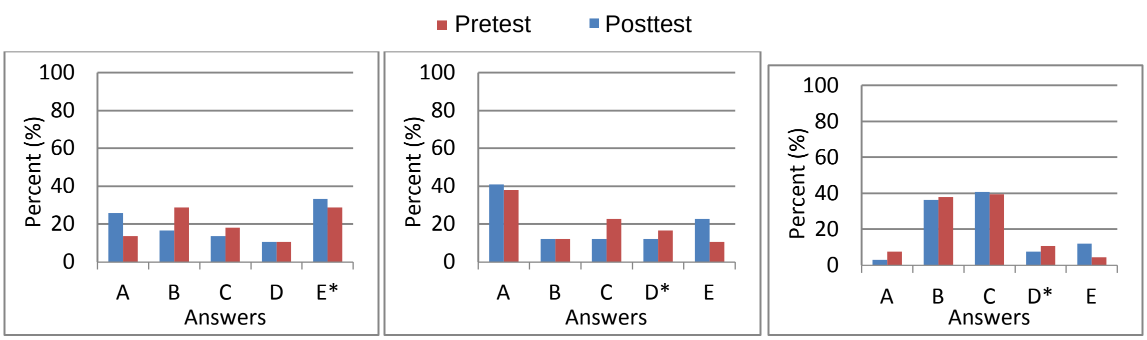

Figure 4.7. Graphical summary of answers for pretest and posttest assessments on Magnetic Force. Correct answers are marked with an asterisk.

The data obtained from questions 10, 11 and 12 were evaluated and shown in Table 4.4. Contrary to the previous t-test results, mean scores showed a significant difference between conditions on pretests results, (t=2.64, p<.05). The biggest difference can be seen in that the experimental condition almost doubled the mean score from the control group. This difference was assessed using ANCOVA statistics; however, the condition variable did not impact the posttest results.

Table 4.4. Results of t-test analysis on pretest and posttest scores questions 10, 11 and 12.

	Condition	Mean	Std. Deviation	Normalized Mean
Pretest	Experimental	.692	.6136	23.07%
	Control	.370	.5649	12.33%
Posttest	Experimental	.590	.6373	19.67%
	Control	.444	.6405	14.80%

4.3 Analysis of Responses by Learning Conditions

Pretests and posttests scores were analyzed by learning conditions. Initial evaluations were performed on the pretests responses to observe if a learning condition had a significant difference compared to the other. First, means and standard deviations were calculated for both learning groups, Table 4.5.

Table 4.5. Means and standard deviations for pretest scores by learning conditions.

Treatments	N	Mean	Std. Deviation	Normalized Mean
Experimental	39	3.31	1.866	27.58
Control	27	3.07	2.303	25.58

Table 4.5 also shows the normalized mean scores in a 0-100 scale. As shown in the previous table, the experimental condition (haptic force feedback) performed slightly better than the control condition.

To verify that there were no significant differences in the pretest scores; results were analyzed and measured using t-test statistics. The results obtained from the t-test model for comparing pretest scores between conditions did not show significant differences ($p>.05$).

Posttest scores were similarly analyzed; first, means and standard deviations were calculated and results are displayed in Table 4.6.

Table 4.6. Means and standard deviations for posttest scores by learning conditions.

Treatments	N	Mean	Std. Deviation	Normalized Mean
Experimental	39	3.44	1.971	28.66
Control	27	3.74	2.443	31.16

Results from the Posttest assessment demonstrate that both conditions improve from pretest to posttest. Although initially (pretest scores) the experimental condition obtained a higher grade, the control condition outperformed the experimental group in the posttest assessment.

After the means and standard deviations were analyzed, a t-test analysis was also performed to verify if there were any significant differences between learning conditions. The t-test analysis showed no significant differences between conditions ($p>.05$).

4.4 Analysis of Responses from Pretest to Posttest

The last analysis performed on the collected data had the intention of observing if any significant differences could be found between the pretest and the posttest scores by learning conditions. First, the experimental group results were analyzed and means and standard deviations were calculated, Table 4.7.

Table 4.7. Means and standard deviations for the experimental condition.

Assessment	Mean	Std. Deviation	Normalized Mean
Score Pretest	3.31	1.866	27.58
Score Posttest	3.44	1.971	28.66

The results from the pretest assessment were compared to the posttest results using t-test statistics. However, although a score's increment can be observed, there were no significant differences found between assessments' scores ($p>.05$). Lastly, the control group results were also analyzed first calculating means and standard deviations, as shown in Table 4.8, and then through t-test statistics.

Table 4.8. Means and standard deviations for the control group.

Assessment	Mean	Std. Deviation	Normalized Mean
Score Pretest	3.07	2.303	25.58
Score Posttest	3.74	2.443	31.16

The control group also showed an increment from pretest to posttest, and after performing the statistical procedure of t-test, a significant difference was found (*t*= -2.550, *p*=.0085). Participants from the control group (e.g. no force feedback) presented a higher mean score than the experimental group. These findings provide evidence that although the control group did not experience the haptic device force feedback, they surpassed the performance of the latter condition.

4.5 Discussion

In summary, the control group had higher achievement scores than the experimental group for three of the four topics (Coulomb's law, Electric force and Field Superposition, and Magnetic Force). This was observed when the mean scores were analyzed from pretest to posttest and compared by learning conditions. While the results obtained from the collected data do not provide a consistent pattern on the learning groups' acquired knowledge when analyzing each of the electromagnetism topics, they do present a more positive conclusion for the control group.

Although the control group presented higher pretest to posttest scores, no significant differences were found when comparing the control group's performance to the experimental group's performance. Possible reasons that could have caused the obtained results vary; for example, as similar to Jones et al. (2003) who also implemented a haptic experiment, the sample size could have affected the possibility of finding significant differences.

Additionally, the complexity of the abstractions and force feedback presented through the computer simulations and the haptic device may have overloaded the working memory of the participants from the experimental condition. While participants from both conditions utilized the Falcon haptic device, only the experimental group experienced the vibrations and impulses that the equipment provided.

Cognitive overload occurs when the information processed exceeds the cognitive capacity of the learner (Mayer & Moreno, 2010). This information could have been presented either by text, audio, images or, in the case of the present study, by tactile channels. Although the dual coding theory states that learners utilize different learning channels (visual and auditorial) when acquiring information, theory also states that each channel has its own cognitive limit (Clark & Paivio, 1991). Based on the cognitive overload theory, it is possible to exceed the cognitive capacity of learners if information is not clearly and easily presented (Mayer & Moreno, 2010). Information not clearly presented requires more cognitive processes, leaving less space for cognitive working memory.

CHAPTER 5. STUDY 2: EXPERT EVALUATION

5.1 Revisions to Learning Materials and Procedures

Based on the results obtained from the first iteration of the present experiment, several modifications were designed and implemented. These modifications are grounded on theories and principles of Multimedia Learning (Mayer, 2005) as well as on expert reviews from experienced physics and technology graduate students and professors. Theories from multimedia learning as well as the implementation of the suggested revisions provided the basis and guidance for the second iteration of this study.

Revisions started by examining the initial set of learning materials and procedures used in the first iteration of the experiment. These revisions carried out a set of improvements and modifications based on grounded literature. First, three treatment conditions were designed (Figure 5.1) to explore if the addition of haptic force feedback presented better results (according to posttest assessment scores) compared to the inclusion of a computer simulation and an instructional courses alone.

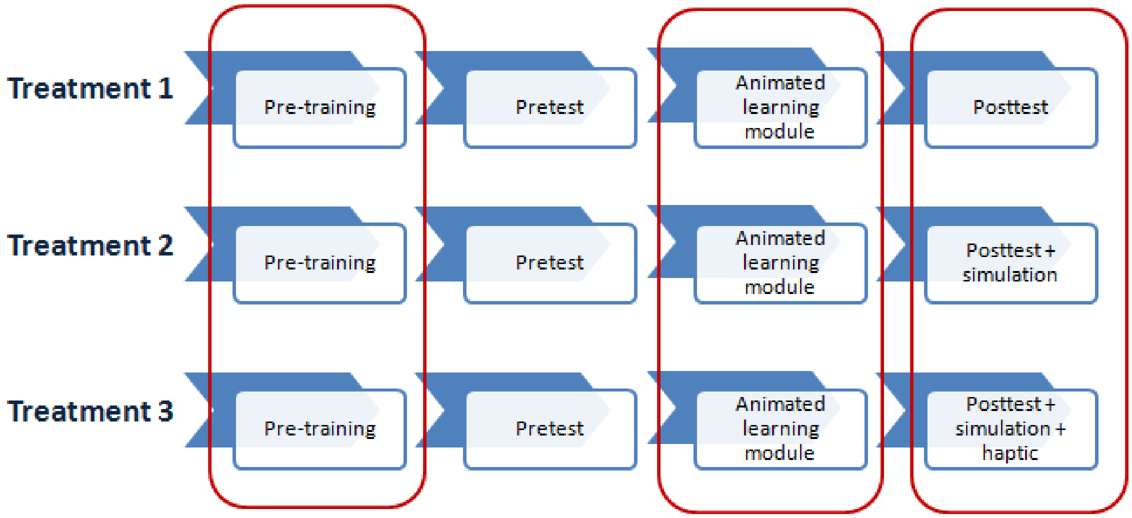

Figure 5.1. Revised treatment conditions for the second experiment iteration.

The treatments included new and modified learning materials: (i) a training session for students to get used to the haptic feedback, (ii) an instructional course created with Microsoft PowerPoint implementing principles of multimedia learning, and (iii) addition of functionality and levels of interaction to the visuohaptic computer simulation called “Charges.exe”, and the Falcon haptic device.

5.1.1 Pre-training Simulation

All of the sample participants were exposed to a training simulation a week prior to the experiment session. The Bar Magnets simulation (Figure 4.1) previously employed during the first iteration of this experiment was used to train participants on the operation of the haptic device. The simulation was proposed to reduce or eliminate the novelty factor from the equipment, as well as to prevent the split-attention effect that the device could possibly cause on students' learning.

The training session was based on the pre-training principle from Mayer (2005). The principle states that training information "provide[s] prior knowledge that reduce[s] the amount of processing needed" from the learner (p. 174). During the training session students were able to explore what a visuohaptic simulation was, how the haptic device worked, feel the provided force feedback and acquire an initial sense of the device.

The addition of the training simulation was also proposed by several experts in instructional design to prevent the split-attention effect. According to Mayer (2005) "instructional split-attention occurs when learners are required to split their attention between and mentally or temporally disparate information, where each source of information is essential for understanding the material (p. 135). The procedure of unifying the information requires more working memory space from the learner to process the different information formats, "leaving less working memory capacity for learning processes such as schema acquisition" (Florax & Ploetzner, 2008, p.216). Students working with the haptic device (tactile information) and with the simulations (visual information) are exposed to experiencing this type of effect due to the different formats the information is presented. However, by providing a training simulation, students are able to grasp the functionality of the device and simulations, and be mentally prepared for the experiment session.

5.1.2 Instructional Course

The second version of the experiment included an instructional course created with Microsoft PowerPoint. PowerPoint presentations are a broadly used tool in the educational field, especially in universities and colleges. Research has proven that students prefer PowerPoint presentations as compared to other presentation materials such as transparencies (Stoloff, 1995; Susskind & Gurien, 1999; Szaba & Hastings, 2000; West, 1997). Additionally, the study from Harknett and Cobane (1997) provided evidence that students preferred PowerPoint presentations because they thought were beneficial and improved their recall.

Although the use of PowerPoint has been debated by several researchers because of mixed results obtained after comparing traditional lecturing versus PowerPoint lecturing, (Creed, 1997; Rocklin, 1997), it has been demonstrated that presentations created with Microsoft PowerPoint provide structure, organization, pacing and time controls to the presented information (Daniels, 1999; Hlynka & Mason, 1998; Mantei, 2000).

The main objective of the instructional course was to explicitly present the E&M concepts related to the visuohaptic computer simulation (Charges.exe) used in the experiment session in an organized and concise format. The instructional course covered two main topics and four subtopics related to electromagnetism:

- Coulomb's Law
    - Electric Charges
    - Electric Forces
    - Electric Fields
- Electricity and Magnetism
    - Electric Fields and Magnetic Fields

The information provided in the course served as an introduction of the concepts rather than their thorough explanation. Several Multimedia Principles for Learning from The Cambridge handbook of multimedia learning (Mayer, 2005) were used as a base line to accurately design and create an engaging and fruitful presentation course. Additionally, several research literatures served as support material of the multimedia learning principles. The use of the principles and literatures guiding the design of the instructional course are described in the rest of the present section.

The instructional course included text, images, animations, and videos providing conceptual information on Coulomb's Law, Electric forces, and Electric and Magnetic fields. Several research studies have proved that useful and relevant graphics and animations improve students' recall (ChanLin, 1998, 2000; Lowry, 1999; Szaba & Hastings, 2002,) A learning principle that also provides evidence that images and graphics improve learning is the Multimedia Principle (Mayer, 2005). According to this principle deeper learning is achieved when there are pictures and words combined rather than only words.

Videos with narrative explanations about Coulomb's Law, and Electric and Magnetic Fields were included in the presentation course to serve as a conceptual support of the textual material based on the Modality Principle (Mayer, 2005). Mayer (2005) states through this principle that deeper learning is acquired when words are presented as narration rather than as screen text. Additionally, Schmidt-Weigand, Kohnert, and Glowalla (2010) referenced a meta-analysis made by Ginns (2005) in which evidence demonstrates that text accompanied by audio explanations is more useful for learners than text and images or text alone.

Besides the content material and the different formats included in the course, the presentation had the functionality of being reproduced in kiosk mode. This capability helped guide participants through the course's content intended order. This feature allowed students to use their own pace when progressing on the course material. The characteristic of kiosk mode is supported by the Self-pacing principle (Mayer, 2005) which states that if a student has control over the rate or progress of the learning material then higher processing of information may occur. Based on this principle, students were able to navigate the course at their own pace through the use of a navigation system (Figure 5.2) The navigation system included arrows and a menu button which appeared at the bottom of the course's slides a few seconds after the content had been displayed.

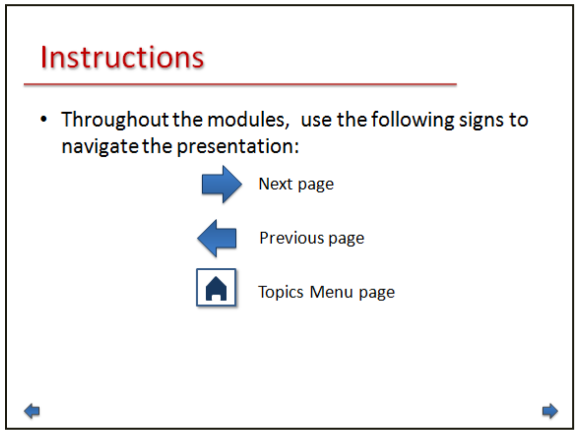

Figure 5.2. Navigation slide.

The course was divided in several sections following the theory of the Segmenting Principle (Mayer, 2005). The Segmenting Principle states that it is better to present learners with a segmented multimedia lesson rather than with a continuous unit. For this reason the instructional course was divided in six units: the introduction, four electromagnetism subtopics and the concluding segment. First, participants were presented with an introduction of the course and main objectives of the research study, Figure 5.3.

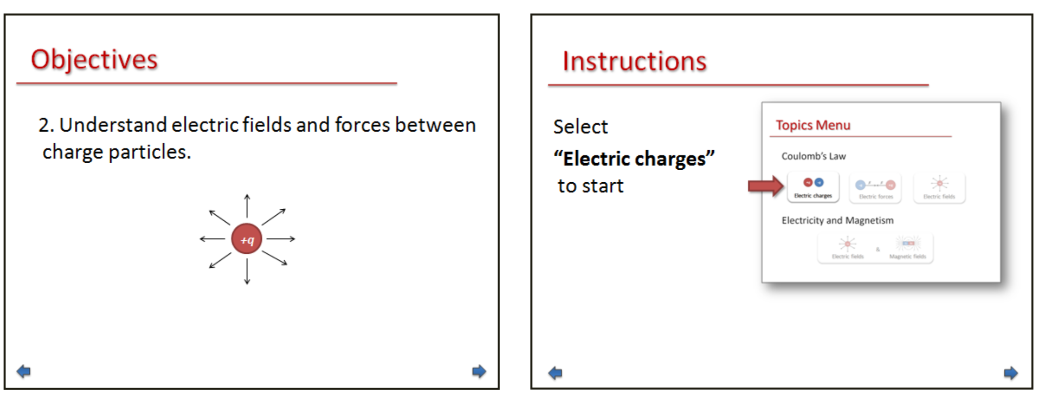

Figure 5.3. Course's objectives and instructions slides.

Then, participants were presented with a Topics Menu slide which introduced, in a simplified and organized format, the course's topics (Figure 5.4).The Menu slide allowed participants to navigate the course in a specific order as a result of the topics buttons being initially disabled. The only button available was the initial topic "Electric charges", which students selected in order to start the course content. As the participants completed a topic, the next topic button was activated. Participants were able to reproduce the topics a second time if the topic had already been completed.

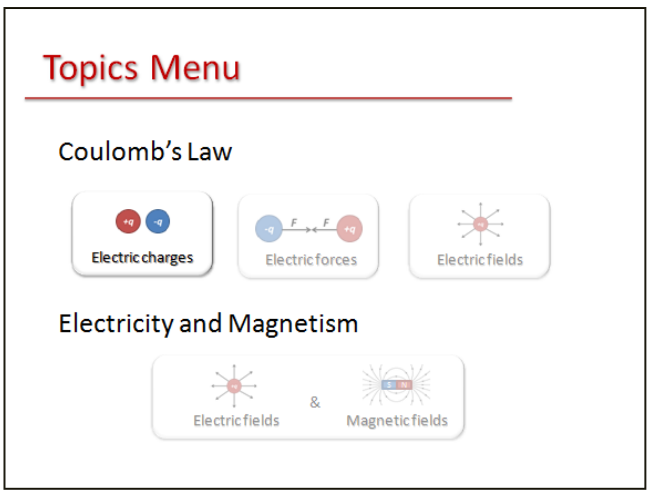

Figure 5.4. Course's Topic Menu slide.

Lastly, participants were presented with instructions on how to initiate and complete the Posttest assessment (Figure 5.5). A hyperlink was created to link the Posttest assessment with the instructional course. The assessment was available for students online through the Qualtrics application.

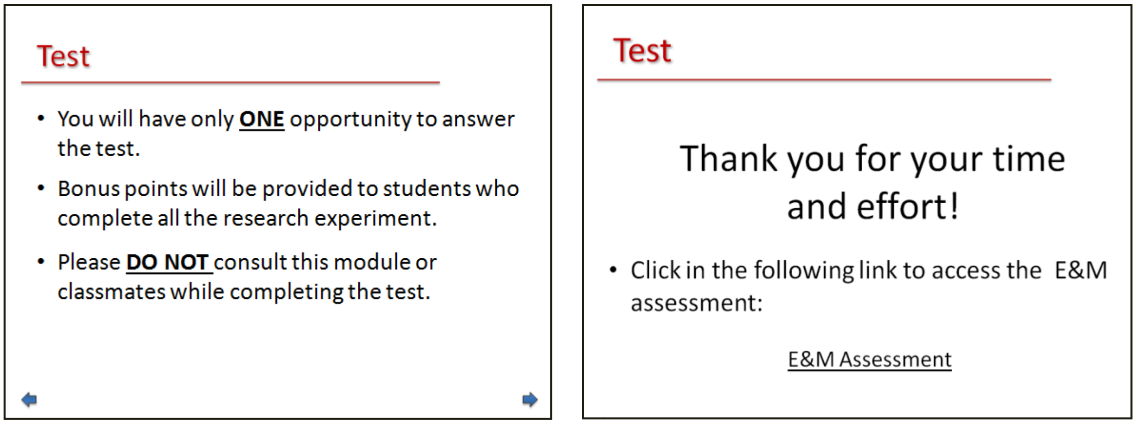

Figure 5.5. Posttest assessment instructions and link slides.

The design and implementation of the different sections of the instructional course were also based on the Signaling Principle (Mayer, 2005). The Signaling Principle states that it is better for learners if cues about the purpose of the presentation are provided. Along with the instructions on the objective of the instructional course and the research study, the course presented several cues throughout its content, such as the electromagnetism topics in a menu-based slide, a Coulomb’s Law formula worked-example, and indications on the end of the course and the assessment to be taken.

5.1.3 Visuohaptic Simulation

Revisions of the learning materials included the examination of the charge particles simulation. The charge particles simulation is a haptic enabled computer simulation that allows users to interact with charged particles through a haptic device. Users “feel” the charges of the particles as they get closer to them when moving the haptic grip. The initial version of the charge particles simulation consisted of two static particles (a negative and a positive particle) and their static field lines (Figure 5.6). Students were able to move a third positive charge particle around the screen by using the haptic grip and experience the electric forces provided by the static particles.

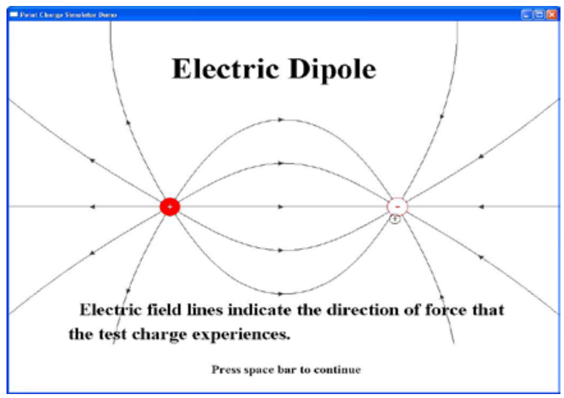

Figure 5.6. Initial charge particles simulation.

For the purpose of the second iteration of the haptic experiment an enhanced version of the charge particles simulation was created. This upgraded version included additional functionality as well as higher interactive features. First, the initial screen of the simulation showed an empty gray area and a bar with ten charged particles, five negative and five positive, Figure 5.7.

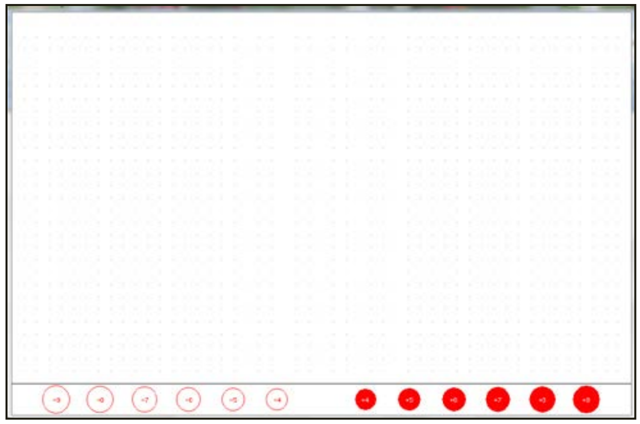

Figure 5.7. Initial window for the Charges computer simulation.

Particles could be moved to the gray space by clicking on one particle at a time with the mouse cursor and releasing it in the gray area. There could be more than one particle with the same magnitude in the gray space, and particles could be placed close to one another. Additionally, by clicking in the gray area next to a particle, the simulation drew the closest particle's electric force vector, Figure 5.8.

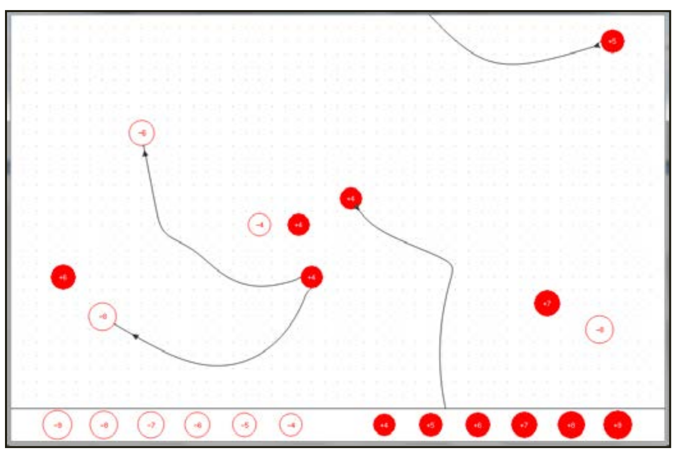

Figure 5.8. Configuration of several charge particles and electric force vectors.

Figure 5.9 shows the behavior of the force vectors of a single negative particle after different places of the gray area had been clicked.

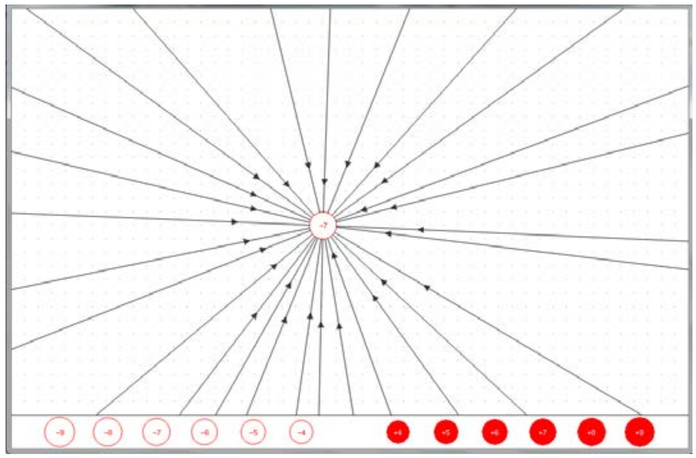

Figure 5.9. Electric force vectors of a negative particle.

The simulation has also the functionality of displaying the electric field lines of the particles located in the gray area. This feature can be observed by clicking on the number “1” key from the computer’s keyboard, Figure 5.10. The electric field lines are represented through arrows, which point outward for positive particles, or inward for negative particles.

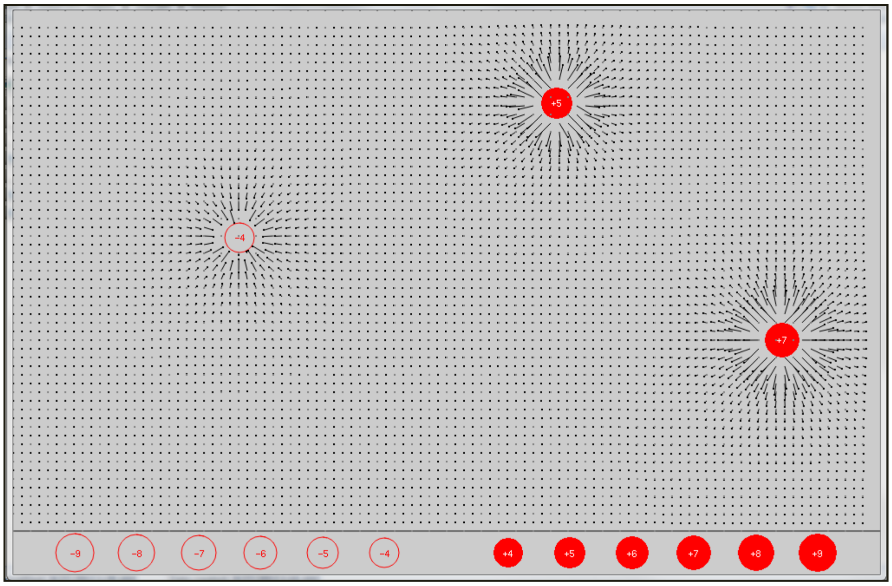

Figure 5.10. Electric field lines of three charged particles.

5.2 <u>One-on-one review interviews</u>

5.2.1 Methods

The initial sample of participants who participated in the one-on-one interviews consisted of two senior physics undergraduate students, two technology graduate students, one PhD physics student, and one Associate Professor in the Department of Computer Graphics Technology at Purdue University. The physics background of the three physics students, as well as of the technology background of the two graduate students and the Associate Professor, provided useful feedback information on the review of the used learning materials.

The Associate Professor has a specialization in the area of graphic virtual interfaces. This background field contributed to the improvement of the graphic user interface of the instructional course, as well as the design of the pretest and posttest assessment.

One-on-one interviews were performed over the course of the first two months of the Fall 2013 semester. The interview sessions took approximately 45 minutes. Interviewees were initially briefed with a description of the research and the materials to be used in the experiment. After the introduction of the learning materials, interviewees interacted with the instructional course and the computer simulation. At this time questions related to specific details of the content as well as the purpose of the study were answered by the interviewer. Interviewees were then presented with the Pre-Post assessment. After all the material had been presented and read, a design review survey was used to collect the interviewee’s feedback and comments (see Appendix B).

The survey consisted of twelve five point Likert scale questions related to the organization, accuracy, relationship, and alignment of the content of the instructional course, the Charges simulation, and the questions from the Pre-Post assessment. The Likert scale was intended to measure the participants’ level of agreement, providing five response levels: Strongly Disagree to Strongly Agree.

Additionally, the survey included five open ended questions where explicit feedback or comments from the reviewers were elicited. When collecting the comments and feedback from the interviewees, the interviewer asked the questions from the survey and made the appropriate field notes in the document.

5.2.2 Results and Revisions

The first interview was done to a PhD physics student. The interviewer presented the learning materials, and as the interviewee observed the content, he prompted comments and questions to the researcher. One of the suggestions was related to the topic Bar Magnets in the instructional course. Initially, the instructional course covered the topics Bar Magnets and Magnetic fields (Figure 5.11); however, the new version of the pre-post assessment did not include these topics.

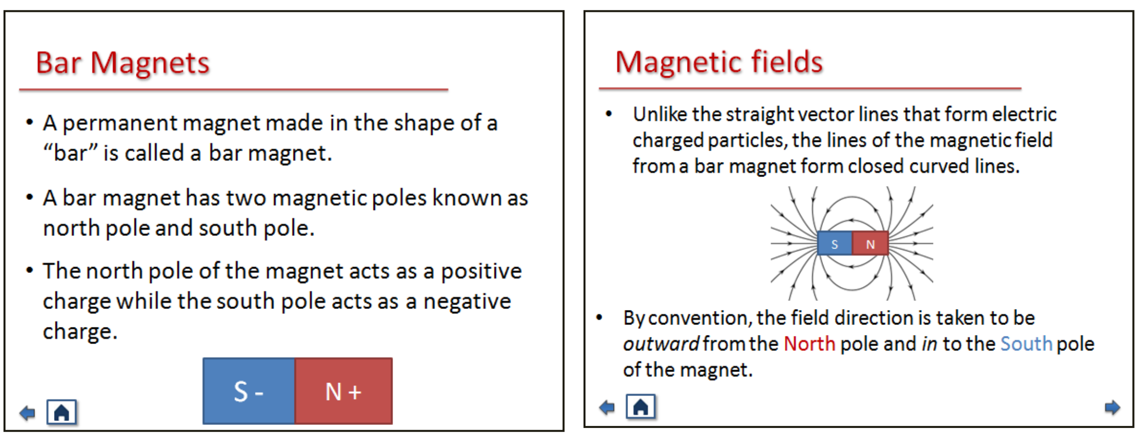

Figure 5.11. Bar Magnets and Magnetic fields course's slides.

The reason was based on the fact that the charge particles simulation did not present material related to Bar Magnets. Considering this suggestion, the interviewer explicitly asked the rest of the physics interviewees about their opinion on the removal of this topic. The topic of Bar Magnets was not eliminated until the end of the revision stage, once all the physics students have agreed on its removal. The only topic left related to Magnetism was a new subject made by the combination of the topics Electric and Magnetic fields. Interviewees agreed on the inclusion of the Electric and Magnetic fields because it demonstrated a relationship between charged particles and their fields.

Several other suggestions made by the PhD interviewee were related to the questions in the pre-post assessment. Before the final version of the test, several items were removed because of their discrepancy between the course content and the computer simulation. An example of this issue was the removal of questions related to Lorentz Force. The interviewee suggested either the inclusion of the topic in the instructional course, or the removal of the questions in the assessment. Since the simulation did not provide enough information to teach the Lorentz Force, it was suggested to remove the questions.

Lastly, comments were made on the wording and accuracy of the course images in relation with the physics concepts. Figure 5.12 displays a course slide presenting Coulomb’s Law before and after the suggested revisions.

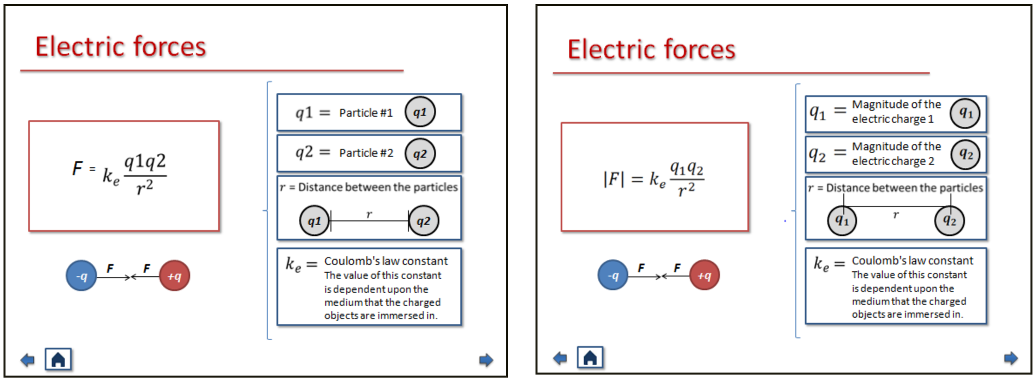

Figure 5.12. Before (left) and after (right) revisions made by Physics experts.

The second and third interviews were made to senior physics undergraduate students. The majority of the suggestions made on the learning materials were targeted towards the instructional course. Following the same interview protocol, the interviewer presented a brief description of the research, as well as the learning materials.

The first undergraduate interviewee suggested changes in the wording of the text, such as modifying “the north pole of the magnet has a + positive charge, while the negative pole of the magnet has a – negative charge” for “ the north pole of the magnet acts as a positive charge and the south pole of the magnet acts as a negative charge”.

Suggestions were also made on the addition of a second image describing Coulomb’s Law formula (already included in one of the slides) later in the course. The interviewee believed that the repetition of information in the instructional course would benefit learners’ recall.

The second undergraduate interviewee provided several comments and feedback on possible test items for the assessment, as well as the inclusion of a worked-example on the use of Coulomb's Law.

Three more interviews were conducted with experts from the Computers and Technology department. Most of the comments and suggestions made by the interviewees from this area were related to design and graphic interfaces rather than to physics content. For example, revisions made by the Associate Professor at the Computer and Graphic Technology department related to the speed and design of the animations included in the instructional course. Due to the fact that the instructional course was created in kiosk mode, including several animations and timing motions, some of these animations were too slow for learners to capture their attention. Field notes were taken on the explicit animations to modify; however, a more in-depth revision was made by the interviewer on the speed of all the course animations.

Additionally, the Associate Professor suggested modifying wording and text, especially in the instructions paragraphs, to create a more concise and clear presentation. Lastly, the interviewee suggested a different distribution and organization of the information presented in the Coulomb's Law worked-example. The main objective of this modification was to create smaller "chunks of information" and to present this "chunks" in different slides. The initial design of the worked-example slide presented all the information in only one slide and used animations to separate the information (Figure 5.13). Later modifications displayed the worked-example and its solution in several slides utilizing animations.

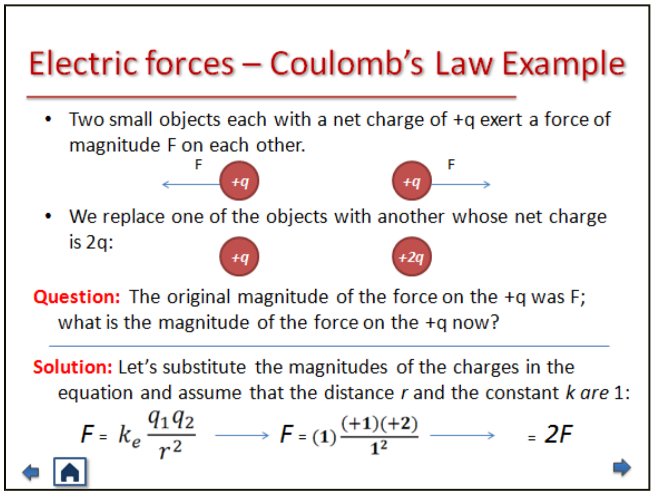

Figure 5.13. Initial design of the worked example explaining Coulomb's Law formula.

The other two interviewees in the area of computing suggested revisions on the design of the pre-post assessment (order of the questions and wording of the instructions), as well as design and wording of the design review survey. These suggestions were implemented in the final versions of both documents.

5.3 Design Review

5.3.1 Methods

The design review of the second iteration of the present research study consisted of a one-hour physics seminar lecture presented to twenty physics Professors and students. Participants' physics knowledge varied from a high expertise (professors) to advance novice (physics master and doctoral students). The main objective of the lecture was to introduce the research objectives, present the new, modified learning materials and collect feedback and suggestions from physics experts before performing the second experiment iteration.

The lecturer initiated the presentation by introducing the theory of Design-based research and presenting the methods and results of the first iteration of the experiment. Next, prior to displaying the new learning materials, participants received printed versions of the design review survey as well the Pre-Post assessment. Participants were then instructed on the use of the survey and the assessment.

The lecturer continued the seminar lecture by introducing the instructional course and its content. Several comments and questions were addressed by the participants throughout the lecture, which were noted by a second researcher on a separate review survey. Once the presentation of the instructional course was finished, the lecturer instructed the participants to read the Pre-Post assessment and relate the recently observed content from the course and the questions from the assessment. Participants were also instructed to write any comment or feedback on their design review survey.

Lastly, three computers installed in the lecture room were prepared with the visuohaptic simulations (bar magnets, original charge particles and upgraded charge particles) to be used by the seminar participants. Each of the computers had a haptic device installed. Participants were instructed by the researchers to manipulate the simulations by using the haptic equipment and to relate the previous two learning materials (instructional course and assessment) to the simulations, and make the necessary comments or notes on the review survey.

5.3.2 Results from the Design Review

Results from the Physics Seminar session were mostly related to explicit wording and content of the instructional course. For example, an important suggestion was related to the Coulomb's Law formula worked-example. Interviewees suggested the modification of the formula's final results variables names to prevent learner's confusion on the formula explanation. In Figure 5.14 the result of the formula is explained by F= 2F; however, the grammatical wording of this statement is incorrect. Experts suggested the modification of the statement to be F_new = 2F_old.

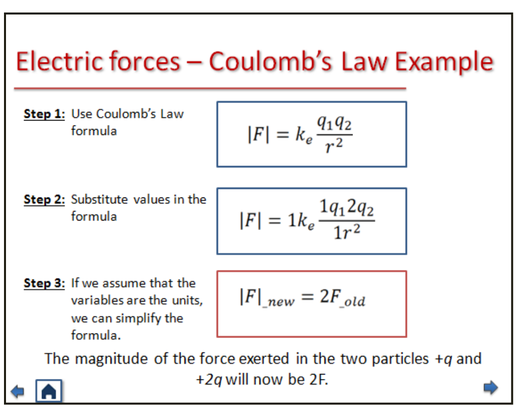

Figure 5.14. Modified version of the Coulomb's Law formula example.

Additionally, experts suggested the removal of different phrases and words that did not need to be added to the course. Lastly, experts had the opportunity to explore and utilize the three available visuohaptic simulations using the haptic devices. Some suggestions were related to the addition of more functionalities and features to the visuohaptic simulations (upgrading 2-D simulations into 3-D and improving the “feelings” and “forces” provided by the device to create a more “realistic” sensation).

CHAPTER 6. DISCUSSION AND IMPLICATIONS FOR TEACHING AND LEARNING

6.1 Experiment Discussion

The first iteration of the experiment provided insight into the deficiencies students possess in regards to their knowledge of electromagnetism, and presented a baseline for researchers to continue exploring the area of haptic technology and electromagnetism in a second experiment iteration. The main purpose of the first experiment was to observe if the addition of haptic force feedback to visual simulations provided benefits the performance of students when assessed in electromagnetism concepts.

At the end of the first experiment iteration the addition of a visuohaptic simulation and haptic force feedback did not provide significant results as to whether students who used these materials learned more than students who did not receive force feedback. In fact, the group who did not receive force feedback from the haptic device performed better in the posttest assessment applied at the end of the experiment. Based on the information collected from this iteration, as well as the analysis and evaluation performed on the data, a second iteration was planned and executed a year after the first experiment.

The second iteration was intended to modify and enhance the previously used learning materials, as well as to explore through the support of physics and graphic technology experts the accuracy of the experiment process, its conceptual content and its alignment with the learning materials and visuohaptic simulation.

The process of creating an instructional course that could provide explicit introductory information in electricity and magnetism was based on the observed deficiencies obtained from the results of the first experiment. According to several research studies (Dega et al., 2013; Maloney et al., 2001; Törnkvist et al., 1993) it is well known that students at the entry university level experience difficulties when learning abstract concepts in the physics field. For this reason, an accurate alignment between the learning materials and the course's content was desired. The creation of the course as well as the selection of accurate items from the pre-post assessments was possible after several interviewees and a design review group of experts analyzed each of the learning items, provided feedback and suggestions, and those suggestions were implemented.

6.2 Implications for Teaching

Implications for teaching abstract concepts such as electromagnetism should focus on the level of difficulty that the concepts provide to learners. For example, according to Chabay and Sherwood (2006) courses often do not present a connection between electricity concepts, which later increases the confusion students experienced as they do not link topics and information. According to research, some methods and techniques that ease this difficulty include the use of virtual simulations. Research has proven that the use of virtual simulations improve or even assimilate students' learning as compared to students who use real physical equipment (Triona & Klahr, 2003). The correct selection of learning materials and physics topics should be a priority for instructors; however, if these learning materials could provide an extra value to student's learning, such as the use of virtual simulations, instructors should consider their use.

Nowadays further developments and research on teaching methods include the use of virtual simulations coupled with tactile devices. The addition of tactile information to visual and audio formats is thought to be beneficial to learners based on the embodied cognition theory (Monuteaux et al., 2005; Sexton et al., 2012). The force feedback provided by haptic devices allows students to "feel" virtual objects that cannot be observed or felt in real life, and according to the embodied cognition theory, students learn not only through their conceptual system but also through their perceptual and psychomotor systems (Adams, 2010).

However, research has also demonstrated that although virtual simulations can improve the learning performance of students, the complexity presented when haptic force feedback is added coupled with the abstractions of the electromagnetism concepts could affect students' cognitive learning. For this reason, instructors should be aware of this possibility and provide the proper learning contexts, experiences and materials when novel technological tools are intended to be used. Ultimately, designing and implementing a conceptually unified learning experience where students explored the different technological tools and content formats providing a better experience and better acquisition of information was the instructor's main goal on the present research study.

6.3 Implications for Learning

Implications for learning in similar instructional scenarios should focus on whether students are cognitively prepared for new educational technology equipment. Even thought nowadays students have a higher level of exposure to new technology and devices than students did in the past, exposure to experiencing different learning effects such as cognitive overload and split-attention effect are still latent. Instructors should be aware that while providing a different and innovative learning technique to students, they could contribute to cognitive overload. The accurate training or guidance on the use of the novel equipment could prepare students' cognitive learning to acquire a higher level of conceptual understanding and prevent these learning issues.

6.4 Implications for Design Based Research

The implementation of novel technology while using a design-based research approach can help researchers create and test new hypotheses, as well as learning theories, on the use and benefits of the investigated devices. Thanks to its several iterations approach, design-based research allows researchers to explore a learning method, tool or design, and build upon the obtained results to generate learning theories and frameworks.

Because design-based research consists on several approaches or processes in which the researchers “implement interventions, […] improve initial designs, and ultimately seek to advance both pragmatic and theoretical” (Wang & Hannafin, 2005, p.6), its implementation is suggested to be performed in naturalistic learning environments where the collection of data and learning experiences can help improve further research iterations.

Implications on using new technology devices such as the haptic device when performing a design-based research experiment should focus on the novelty of the equipment, previous literature on its use, as well as the possible effects the device can cause in students learning.

CHAPTER 7. CONCLUSIONS AND FUTURE WORK

7.1 Conclusions

The data obtained in the first iteration of this study showed mixed results when comparing the performance of the experimental and the control group of freshmen students tested on electricity and magnetism concepts. Unlike the control group who was exposed to only visual simulations, participants from the experimental group were presented with visual simulations coupled with haptic force feedback. During the first research treatment, participants utilized two simulations, one related to magnetism and one related to charged particles, and completed a pre-post evaluation tool.

Students' learning was assessed with a pretest and posttest survey assessment. Results from both condition groups were examined and analyzed by questions' topics, by pretest to posttest based on group conditions and by pretest and posttest assessments. Pretest results were initially evaluated and no significant differences were found by learning conditions. Similarly, posttest responses from each condition showed no significant differences. However, significant differences were found between pretest and posttest scores for the control condition. The control group participants' scores increased significantly from pretest to posttest. This was not observed with the experimental group scores. In conclusion, results suggest a better performance of the control group in three of the four topics when compared with the experimental group responses. Likewise, pretest and posttest scores resulted in the control group having higher mean scores (but not statistically significantly higher) than the visuohaptic group. It is possible that if the study was repeated with higher sample sizes a statistically significant difference could be measured.

The second iteration of this design-based research experiment was based on improving the previously used learning materials and experiment processes to create an enhanced experiment design. Several interviews with physics and technology experts provided feedback and suggestions on the presented material, which later supported their performed modifications. The modifications included the adaptation of different physics wording, the revision of images and animations, as well as the adjustment of the functionality of the instructional course and computer simulation.

7.2 Limitations for the Study

The present study had several limitations. In the first version of the experiment, students completed the pretest assessment individually as a take-home task. Although they were instructed not to consult any external material or resources, lack of evidence does not allow creating any judgment. Likewise, since both assessments were answered voluntarily, participants with incomplete items were disregarded from the overall sample. This later presented an impact on the condition samples size affecting the control group.

A third limitation was the extra credits participants received for completing the pretest and post assessments. Used as a motivation to participate in the experiment, participants were offered with extra credit after the accomplishment of each task (e.g. pretest and posttest). However, since the extra credit was not related to the score obtained in either the pretest or posttest assessments, students may have failed to provide enough effort and willingness to obtain a significant grade in the tasks.

During the second iteration, in the design-review stage, a fourth limitation was the background expertise of the interviewed population. This limitation can also be related to the background history of the participants' sample used as a pilot study during the first experiment iteration. Because the main purpose of the design stage was to consult physics experts and gather their feedback on the content of the learning materials, the interviews and the seminar lecture focused primarily on physics students and physics Professors. However, an observed limitation was the lack of feedback collected from a sample that most accurately described the true experiment participants' sample (e.g., freshmen engineering students).

Finally, the results of this study should not be generalized until further research is made with haptic technology and the study is replicated with a larger sample size.

7.3 Future Work

Future work includes further research in the area of haptic technology and its possible benefits to cognitive learning. The next step following the implementation of the second iteration of the experiment will be to analyze statistically the collected data. Results will provide more information on whether the use of haptic technology is beneficial for cognitive learning or not.

If results prove to be significant, further research will focus on implementing new experimental designs to teach similar electromagnetism using the haptic device with widely used computer simulation such as the ones developed by the University of Colorado and their Physics Educational Technologies (PhET).

Future work also includes the implementation of a third experiment iteration where the independent variable (treatment conditions) can be altered to create a new treatment group. The results collected from the new treatment can be analyzed and compared using similar statistical methods to the data collected from the learning conditions of the second experiment iteration.

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APPENDICES

Appendix A. Pre-Post Assessment.

Table A1. Questions and correct answers from Pretest-Posttest assessments. Correct answers are marked with an asterisk.

Coulomb's Law

Two small objects each with a net charge of +Q exert a force of magnitude F on each other.

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

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

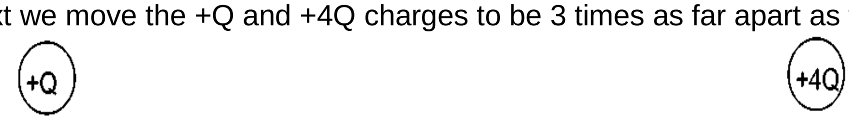
   (a) 16F (b) 4F* (c) F (d) F/4 (e) other

---

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

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

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



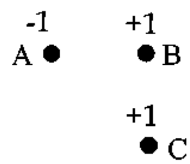
3. Now what is the magnitude of the force on the +4Q?

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

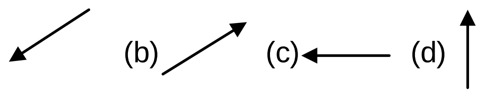
Table A1. Continued.

Electric Force and Field Superposition

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



(a) (b) (c) (d) (e) None of the above*



5. In the figure below, positive charges q2 and q3 exert on charge q1 a net electric force that points along the +x axis. If a positive charge Q is added at (b,0), what now will happen to the force on q1? (All charges are fixed at their locations.)

(a) No change in the size of the net force since Q is on the x-axis.
(b) The size of the net force will change but not the direction.*
(c) The net force will decrease and the direction may change because of the interaction between Q and the positive charges q2 and q3.
(d) The net force will increase and the direction may change because of the interaction between Q and the positive charges q2 and q3.
(e) Cannot determine without knowing the magnitude of q1 and/or Q.

Table A1. Continued.

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

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

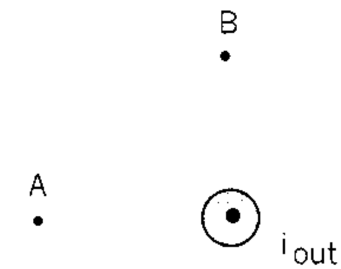
Magnetic Field Caused by a Current

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

(a) ↑* (b) ← (c) → (d) ↓ (e) None of the above

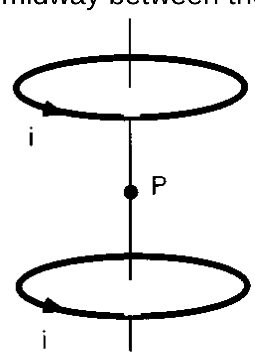
8. The diagram shows a wire with a large electric current i (⊙) coming out of the paper. In what direction would the magnetic field be at positions A and B?

Table A1. Continued.



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

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



(a) ↓ (b) → (c) ↑ * (d) ← (e) Zero

Table A1. Continued.

Magnetic Force

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

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

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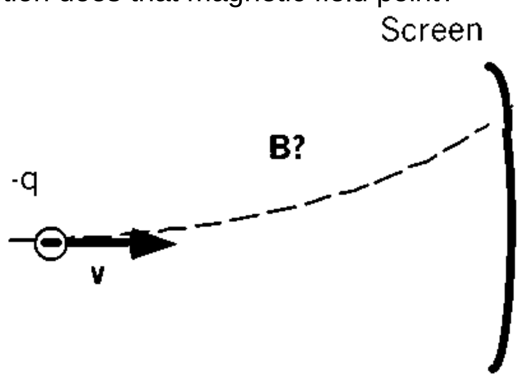
11. An electron moves horizontally toward a screen. The electron moves along the path that is shown because of a magnetic force caused by a magnetic field. In what direction does that magnetic field point?

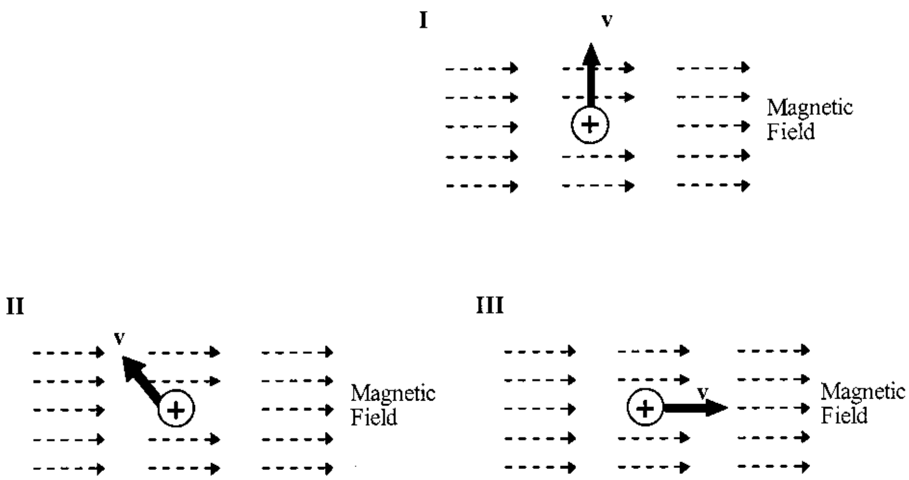


    (a) Toward the top of the page
    (b) Toward the bottom of the page
    (c) Into the page
    (d) Out of the page *
    (e) The magnetic field is in the direction of the curved path

---

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

Table A1. Continued.



(a) I = II = III (b) III > I > II (c) II > I > III (d)I > II > III * (e) III > II > I

Appendix B. Design Review Survey

Dear Professor,

Thank you for your help in evaluating the instructional media about Electricity and Magnetism. First, we would like you to please explore the instructional course called “Electricity and Magnetism module”. Secondly, we will appreciate if you could explore the document Charged Particles Simulation Explanation; please click on this link to open the file (please use the password “haptic”). This document provides screenshots and information on the performance of the Charged Particles simulation. Then, we kindly ask you to reflect on the relation between the instructional course, the virtual simulations, and the assessment task called “Pretest-Posttest Assessment” located in this link (please use the password “haptic”). Finally, we would like you to please respond the following survey.

Once again, thank you for your participation.

Please provide your area of expertise:
____

Students’ learning objectives:

- Demonstrate conceptual understanding of electric charge particles and their characteristics.
- Demonstrate conceptual understanding of electric fields and forces between charge particles.
- Demonstrate conceptual understanding of magnets and their magnetic fields.

After reviewing all the learning materials, please indicate, using your best judgment, the degree to which the content meets the following criteria.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Comments
Instructional Course						
Are the learning objectives clearly stated?						
Is the content well organized?						
Is the content accurate?						
Is the reading level adequate for the target audience (freshmen)?						

Does the learning material cover the subject in sufficient breadth and depth to meet the learning objectives?						
Is the course free of production errors, such as broken links, missing graphics, and typographical errors?						
The combination of pictures and texts is done in such a way that it may hardly result in learner's cognitive overload						
Computer Simulations						
The content well organized						
The material is easy to understand						
There is a high relationship between the instructional course content and the computer simulations' content						
Assessment						
All questions in the assessment are related to the instructional materials (the pptx)						
All questions in the assessment are related to the simulation tools						

1. Please provide feedback on the alignment between the power point lecture and the assessment questions. Are there any other topics that are being assessed but not presented as part of the power point lecture? Please provide a rationale.

2. Please provide feedback on the alignment between the assessment questions and the simulations. Are there assessment questions that need to be reviewed or removed from the assessment? Please provide a rationale.

3. What suggestions do you have for improving the alignment between the content of the power point, the assessment instruments and the simulations used?

4. What suggestions do you have for improving the quality and accuracy of the information covered in the course?

5. What suggestions do you have for improving the quality of the information covered in the simulations?